When Climate Change Determines International Agreements. Evidence from Water Treaties

F. Candau[*], T. Gbandi[†]

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Abstract

Is climate change pushing governments to implement international treaties for the management of common resources? Yes, at least with respect to the Water Treaties (WTs) on common basins and rivers studied in this article. We found that climatic conditions, such as higher temperatures and lower precipitation, directly lead to a higher likelihood of signing WTs in the short, and even more so in the long run. By analyzing the impact of changes in climatic conditions observed between 1961-1975 and 1993-2007, we found that a one-degree Celsius increase in temperature has resulted in a 16.6% increase in the likelihood of signing WTs. These results are obtained for treaties related to environmental protection and economic development, and they also hold for "strong" treaties.

JEL: F1, Q2

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[*] Universite de Pau et des Pays de l'Adour, E2S UPPA, CNRS, TREE, Pau, France. Mail: fabien.candau@univ-pau.fr

[†] Univ Jean Monnet, GATE

1 Introduction

The effect of climate change on water is a major issue for humanity, if only because most of the world's agricultural production depends directly on this resource (IPCC, 2007). Transboundary waters account for more than the half of the freshwater flows in the world (UN-Water, 2020), 40 percent of the world's population depends on these shared basins (FAO, 2022), and 151 countries have a territory within at least one of these rivers and basins.

Faced with the urgency of the climate crisis that could lead to a 40% shortfall in water availability by 2030 (UN-Water, 2020), it seems crucial to better understand how governments have reacted to past weather/climate fluctuations. There is mounting evidence to suggest that climate change, and its associated extreme weather events, such as heatwaves, droughts, and flooding, have prompted the creation of new national environmental regulations (Gagliarducci et al., 2019, Elliott et al., 2022). However, despite this growing body of knowledge, little is understood about the impact of climate change on international treaties, specifically Water Treaties (WTs), which govern the use and management of transboundary waters.

To illustrate the potential relationship between WTs and climate change, Figures 1.A and 1.B present two aspects: On the one hand, the increase in temperature (bar, left axis) as well as the increase in water stress (dot, right axis)[1] in the world since 1961; and on the other hand, the cumulative number of treaties signed. While it is noteworthy that at the outset of the period, WTs were predominantly concerned with treaties centered around dams and economic development, the last few decades, which have seen a rise in global temperatures, have also witnessed a considerable surge in the number of environmental treaties.

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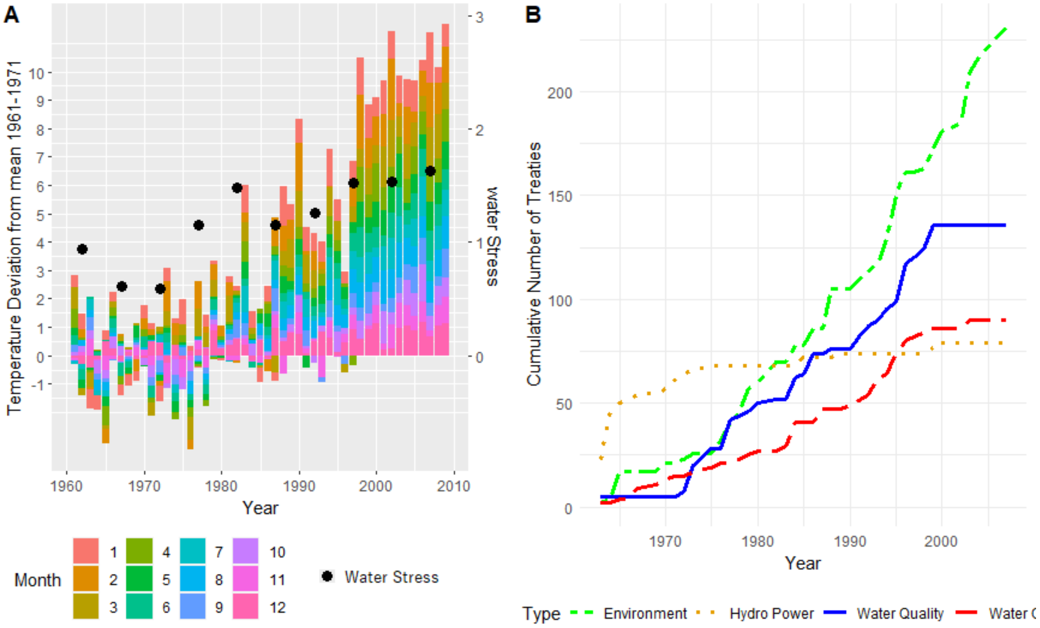
[1] The indicator of water stress (FAO Aquastat database) provides an average of the freshwater withdrawal as a proportion of available freshwater resources over a period of four years. We divide this indicator by ten to obtain a readable figure. It is noteworthy that the number of countries at the start of the period is limited, so that the increase in water stress over time also represents a composition effect linked to the fact that new countries with more water stress are introduced into the database.

Figure 1: Climate Change and Water Treaties



Panel A: Temperatures are from the World-Clim project. Each color of a bar represents the temperature difference from the 1961-71 average by month (and in Celsius). For example, in January 2009, the average temperature over the Earth was about 12°C, while the average January temperature over the 1961-71 period was 11.3°C, so the deviation is equal to 0.7°C, represented by a colored square in the 2009 bar in Figure 1 (left axis). The water stress indicator (right axis) is from the FAO Aquastat database. Panel B: The cumulative number of treaties comes from the International Freshwater Treaty Database.

However, correlation is not causation, and the previous discussion may be based on common logical fallacies due to sample bias (temperature deviations from 1961-1971 may not be representative), reverse causation (in particular regarding water stress), and omitted variable bias (such as agricultural specialization, which may explain both water stress and the signing of water treaties).

To our knowledge, few studies have analyzed the causal impact of climate change. Some research has provided evidence on the effect of water scarcity on the motivation to sign water treaties (e.g., Dinar et al., 2011). However, data on water scarcity are only available and reliable for the most recent period, which makes it difficult to conduct a long-term analysis. Consequently, the effect of climate change on WTs cannot be analyzed with the current indicator of water stress/scarcity.[2] Furthermore, water scarcity is likely to be endogenous to various variables that explain WTs, such as population size, economic specialization and/or level of development. Besides, it may be subject to reverse causality, as a water treaty to preserve water resources can influence water availability. We therefore take a different approach by examining whether changes in precipitation and in temperatures year after year, and over a long period of time,[3] have had an impact on the likelihood of signing WTs. As several studies have shown, people often infer evidence of climate change from perceived weather anomalies (Borick and Rabe, 2017). In particular, the fact of having experienced dramatic changes in temperature/precipitation has an impact on one's belief and knowledge about climate change (Sambrook et al., 2021). As a result, weather fluctuations potentially exacerbate the lack of cooperation between governments regarding the preservation of common water resources.

We use panel data to exploit variations in climate variables across time within countries accross the world (124 countries) between 1961 and 2007. We compute a bottom-up indicator of temperatures and precipitation at the highly disaggregated scale of a 2.5 arc-minute grid (or approximately 21 km^2) along the land surface corresponding to the river basin of each country. The objective is to determine whether climatic shocks have a causal effect on the likelihood of signing WTs and how this effect evolves over time. This fine-grained analysis at the local level is necessary pre-

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[2] The literature on water scarcity indicators (also called indicators of "water pressure", "water stress", "water capability") is huge, however often limited to recent years (see for instance Gain et al., 2016, Rosa et al., 2020, Vallino et al., 2020) due to the lack of historical data. Indeed water scarcity, which can be defined simply as a situation where freshwater demand exceeds its availability, turns out to be very difficult to compute once we consider the multidimensional factors that affects both the demand, the access and the availability of freshwater. Candau et al. (2022) provides a sophiticated indicator of water scarcity all over the world at a very disaggregated geographical scale, but it is unfortunatly available for the year 2000 due to the lack of data.

[3] By approximating climate change by the fluctuation in temperatures and precipitation we follow a longstanding literature in economics and in political sciences. See for instance Burke et al., 2015 on the link between economic productivity and temperatures and Dell et al. (2014) for a survey.

cisely because negotiations on transboundary waters concern the regulation of water flows that are strongly impacted by geolocated climatic conditions. Flooding, for instance, is more recurrent along these transboundary waters, and draughts have dramatic consequences in these regions that are often specialized in agriculture production (in particular regions with a lack of water infrastructures).

We find that precipitation and temperatures have a significant effect on countries' likelihood of cooperating on international freshwater resources. The effect of precipitation is negative while that of temperature is positive, indicating that water stress is one of the channels mediating how weather conditions influence water treaties. We verify this result by using several different variables of weather fluctuation and under different specifications and controls. We also find that "strong" treaties, defined by the low number of members (thus reducing the cost of cooperation) or their content (obliging the parties to modify their national laws and/or to enforce the treaty), are influenced by climate change. For instance, we exploit the temporal dimension of our sample by analyzing the effects of climate over two different time periods: the period 1961-1975 during which climate change was not yet a serious concern, and the period 1993-2007 during which global warming became more central. We also provide a more general analysis by leading estimations on a decade basis. Comparing the estimates between this long run analysis (called "in long differences") and our year-to-year estimation (called the "short-run version"), enables us to highlight whether river treaties represent a strategy for adaptation to climate change. We find that the long run adjustment to change in climate has indeed exceeded the short run adjustment. For instance, a one-degree Celsius increase in temperature increases the likelihood of signing WTs by 16.6% in the long run, *versus* a 2% increase obtained in the short run. To test whether our findings differ according to the type of river treaty, we also provide results after classifying treaties according to their contents. We find that a warmer climate increases the likelihood of WTs almost irrespective of the objectives, whether based on environmental protection or on economic development.

Regarding the literature, we add to the work of several authors. Tir and

Ackerman (2009) analyze how political institutions (preponderant power distribution, democratic governance) increase the likelihood of cooperation on international freshwater resources between contiguous riparian states. Dinar et al. (2010) find that the water supply variability in international bilateral basins fosters international cooperation. Dinar et al. (2011) show that the relationship between water scarcity and cooperation follows a bell-shaped curve, with more treaties in areas where water scarcity is moderate. Zawahri et al. (2014) analyze treaties regarding their content in order to study the factors influencing treaty design. We extend these works in terms of both the data used and the methodology developed. Regarding the econometric approach, we intensively used country fixed effects and bilateral fixed effects not yet used in the literature on river treaties, enabling us to reduce the omitted variables bias. We also enrich the results of the literature by analyzing treaties according to their contents and natures (weak versus strong). Finally, the "long differences" approach presented in Schlenker and Roberts (2009) and Burke and Emerick (2016) in their analysis of conflicts has never been used before to analyze the adaptation of international cooperation on water treaties (and other kinds of international agreements).

The rest of the paper is organized as follows. In Section 2, after a brief presentation of WTs and the related literature, we present our baseline specification. In Section 3, we consider the effects of temperatures and precipitation on the likelihood of signing WTs in the short run. We also conduct several robustness tests. Section 4 investigates whether river treaties represent a policy for adaptation to climate change in the long run. Section 5 concludes by discussing the meaning of these results in relation to climate change.

2 Water treaties and climate in the short run

2.1 WTs Around the World

International river negotiations and treaties have a long history. In the 20th century, some basic principles were established by the Institute of International Law (IIL) in 1911, among which was the rule prohibiting the unilateral and detrimental exploitation of international basins and the requirement to develop transboundary cooperation. In 1966, the International Law Association advocated an "equitable utilization" of shared watercourses and proposed different practices to manage water resources (public participation, flexible allocation methods, conflict resolution). In 1997, the United Nations General Assembly adopted the United Nations Convention on the Law of the Non Navigational Uses of International Watercourses. In Article 32 of this treaty, the principle of "non-discrimination" is stated, providing recourse for foreigners experiencing transboundary harm to seek compensation in the jurisdiction where the alleged harm originated.

This convention followed the UNECE Water Convention[4] adopted in Helsinki in 1992 and amended in 2003 in order to allow accession by countries outside the UNECE region. These two global conventions promote the development of institutions that foster sustainable development. Europe is perhaps the most advanced continent, since the majority of basin countries have ratified the UNECE Water Convention with the aim of facilitating cooperation in order to ensure the sustainable use of transboundary water resources. Countries in North America have also signed a significant number of treaties with notable legal principles in the governance of basins.

In Southern Africa, the Water Protocol has been signed by members of the Southern Africa Development Community. Finally, many African countries have signed the African convention on the Conservation of Nature and Natural Resources that includes provisions on water. In Asia, treaties are often bilateral, such as the agreement between Kazakhstan and China, or the agreement between China and Russia on the management and protection of transboundary rivers.

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[4] More precisely called the Convention on the Protection and Use of Transboundary Watercourses and International Lakes.

2.2 Different types of Treaties

Water treaties are a sub-classification of what are often called International Environmental Agreements (IEAs). The growing number of these IEAs has long been a surprise for economists (Kolstad and Toman, 2005). Starting from the assumption that IEAs are fully enforced, the literature has seen the increasing number of IEAs as a puzzle, because these kinds of agreements, which aim to finance a public good to manage a common resource, are prone to the free-rider problem (e.g., Dixit and Olson, 2000).

One way to avoid free riding behaviors is to establish significant sanctions to prevent deviations from the enforcement of the treaty. Another solution, in the spirit of Ostrom (1990), is to build common institutions between signatory members that manage the river in a decentralized way. Several WTs that use one of these two solutions are often considered as "strong" treaties. Indeed, some treaties contain technical/financial cooperation and/or monitoring provisions (e.g., mechanisms to monitor treaty compliance), and define the compensation schemes applicable in exchange for water rights or access. They include a) regulatory treaties that set rules to prescribe or proscribe actions (water allocation *versus* pollution emissions), b) programmatic treaties in respect of a common program (e.g., dam construction), and, c) more general treaties that set out principles and norms for cooperation in transboundary basins. Some agreements specify the establishment of a common commission which institutionalizes bargaining between members.

One consequence of these strong agreements is that they often succeed in achieving the goal established in the treaty. For instance, in countries that shared the Rhine and the Meuse rivers, environmental quality has substantially increased since the 1980s due to formal institutions that manage the river basins (see Faure and Partain, 2019). A series of negotiated agreements between Mexico and the U.S. concerning Colorado (since the original treaty of 1944), are also considered to have improved the governance of the common resource (Wilder et al., 2020). Finally, some treaties are negotiated with the help of international organizations, which guarantee to a certain degree the strength of the treaty since future funding is often conditional upon to the enforcement of the treaty (Bapat and Morgan, 2009). For instance, the Nile Equatorial Lakes Subsidiary Action Program (NELSAP) of the Nile Basin Initiative (NBI) has been supported by the World Bank since its inception in 1997. The Indus Waters Treaty signed in 1960 between India and Pakistan was also brokered by the World Bank to delimit the rights and obligations of countries concerning the use of the waters.

However, many WTs are considered as “weak” in the sense that they are signed but not ratified (and sometimes reneged on) or are too vague to be effectively implemented. For instance, the framework for general cooperation signed between Egypt and Ethiopia in 1993 over the Nile only specifies general principles such as in Article 5: “Each party shall refrain from engaging in any activity related to the Nile waters that may cause appreciable harm to the interests of the other party”. An example (among many) of treaties that are not always enforced is the agreement signed by Burundi, Tanzania and Rwanda for the establishment of an organization for the management of the Kagera river basin. In this treaty, the contribution of each member is specified as along with the headquarter of the commission and its goal, but as of 2007 (the last date in our sample), none of these actions had yet been carried out.[5]

2.3 Empirical strategy

The most common empirical strategy to analyze WTs has been a cross-sectional approach. Identification is based on the assumption that the populations sharing a basin in different countries are identical in all respects, except concerning the variable of interest once controls are introduced for the observable economic, institutional and political correlates of treaties. More precisely, the following specification has been used:

$$\Gamma_{ij} = \alpha X_{ij} + \beta Z_{ij} + \varepsilon_{ij}. \tag{1}$$

where Γ_{ij} is a dummy variable, based on the signature of a water treaty, that aims to capture a cooperation relationship between the two riparian

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[5] The database on WTs states that “it is not clear if this treaty ever entered into force”.

states on the long run. For instance, in Dinar et al. (2010) this dummy takes one if at least one treaty exists on any issue over their period of analysis (1961–1990), and zero otherwise. As a robustness check, authors also use the number of treaties. X_{ij} is the variable of interest that varies according to the different studies. In Dinar et al. (2010), it is an indicator of water scarcity/variability captured by runoff and precipitation variability. They find a significant positive coefficient and conclude that the water supply variability in international bilateral basins fosters international cooperation.[6] Finally Z_{ij} is a vector of different controls (conflicts, power asymmetries, etc.).

This cross-sectional approach, also adopted by Neumayer (2002), Dinar et al. (2011), Stefano et al. (2012), has the advantage to considers long-term trends by analyzing long range mean values over the period covered. However, while providing interesting results, it has at least two shortcomings. The first is the classical bias of omitted variables and the second concerns the long time period considered. Indeed, the assumption that all other correlates of WTs are independent of climate variation may be difficult to support over several decades. The timing of the explanatory variable fluctuation is unlikely to be independent of the timing of changes in confounding variables over a long period of time. Even informal institutions have the time to adjust to climate variation in the time lapse of fifty years which is often the time span analyzed. Furthermore, the lack of data on water scarcity for different years (and even decades) and for several countries implies that the average found in the cross-section analysis is not accurate for all countries. The measurement error is likely to invalidate the causal identification strategy that aims to analyse the effect of water scarcity in the long run.

One possibility is to use panel data on a year-on-year basis, assuming that these two problems are less acute (or easier to resolve). This empirical strategy has been adopted by Tir and Ackerman (2009), who estimate Equation (1) by adding the time dimension. They compute a polled regression, without fixed effects and without specific/separated controls for

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[6] See also Zawahri et al. (2014) that analyze treaties according to their content in order to study the factors influencing treaty design.

countries i and j. This paper provides many interesting results, such as the fact that WTs go hand in hand with asymmetrical power distribution, economic interdependence, democratic governance, and water availability. However, the full potential of panel data technique has not yet been used: in particular, the conditions needed for causal inference are not met, because there are many ways in which countries i and j differ that are not taken into account in Equation (1). Furthermore, as recognized by Tir and Ackerman (2009) (see their Footnote 10), due to "severe data limitations", their variable of water availability is based on several problems, for instance "the total amount of water available per country is relatively invariant over time". By not studying the variation of water scarcity, this literature has logically not analyzed the effect of climate change.

We propose instead to estimate the following equation:

$$WT_{ijt} = \alpha.Clim_{ijt} + \beta.Clim_{it} + \mu.Clim_{jt} + Z_{ijt} + f_{ij} + f_{y(i)t} + f_{y(j)t} + f_{ct} + f_t + \varepsilon_{ijt} \tag{2}$$

Our analysis then differs in many respects.

First, the difference between Eq. (2) and the one used in the literature is the introduction of a large set of fixed and time varying effects in order to reduce problems of omitted variables. Since many determinants of WTs are unobserved, hard to measure or endogenous, we need to use all the apparatus of the panel analysis to determine whether a climatic shock has a causal effect. Hence, we use income group-year effects ($f_{y(i)t}$ and $f_{y(j)t}$, where the income groups are from the World Bank and concern High income, Low income, Lower middle income and Upper middle income categories),[7] continental time varying effects (f_{ct}, where c represents Africa, Americas, Asia or Europe), country-pair fixed effects (f_{ij}) and year specific effects (f_t). Country-pair fixed effects account, for instance, for institutions, political and economic variables that determine a specific bilateral relationship throughout the period analyzed. Without these fixed effects, the direct effect of climate change may be a naive interpretation

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[7] Cooperation can be boosted by the level of development or by the specialization of countries.

of a relationship that fails to take into account the contemporaneous and geographical contexts of i and j. Income-year group effects take into account any differences or similarities in the level of development between countries that vary over time, and may influence the likelihood of signing WTs. Continental-year effects control for regional shocks at the continental level. Since some rivers have a continental scale such a control seems necessary.

A second difference between our analysis and the literature concerns our explanatory variables. We focus here on weather variations (temperature and precipitation) while the literature has mainly used indicators of water scarcity. As we have already pointed out, measures of temperature and precipitation are much more reliable than indicators of water scarcity. More precisely, the term $Clim_{ijt}$ refers to the mean temperature and mean precipitation that affect the country-basins ij each year t. We also use other variables defined at this dimension, such the number of hottest and rainiest months (defined above the decade's mean level) of the river basin ij, as well as the number of drought and flood events that affect basins i and j at time t. Finally, we take the highest temperature (and precipitation) variation among the pair to determine the country in the pair that faces the highest change in each given year, and then use the weather variables of this country for that year. This variable thus contains data defined on i and j depending on the year. Our main coefficient of interest is α for these different variables, which enables us to measure the effect of these weather fluctuations $Clim_{ijt}$ at the basin level on WT. We expect an increase in temperature and a decrease in precipitation to have a negative effect on water scarcity, which could influence the likelihood of signing WTs.[8]

We also consider that temperatures and precipitation can capture determinants of the signature of WTs that go beyond water scarcity. For example, individuals have limited information about water scarcity, while they observe precipitation and temperatures on a daily basis, so voters

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[8] We only use indicators of water scarcity as a control because these indicators often have limitations in terms of the number of countries and the number of years. For example, the data in the FAO database, Aquastat, are four-year average measures of water stress and are available for only a handful of countries in the 1960s (and even in the 1970s).

may be more influenced by these variables than by the actual level of water stress. While there is no analysis on this specific topic, there is some evidences in behavioural sciences that people's personal experience of weather anomalies such as temperature fluctuations modify their perceptions of climate change, making the risk more tangible, which in turn promotes environmental actions (Bergquist et al., 2019, Sambrook et al., 2021). Depending on their prior experience, weather fluctuations also influence lawmakers (Elliott et al., 2022). Finally, water treaties can also be signed by politicians who want to signal to their citizens that they are taking action against climate change perceived through weather conditions. In other terms, treaties may be a strategical variable for politicians that can be used to manipulate information about them within the perspective of an election (Battaglini and Harstad, 2020 propose a model that follows this argument).

Finally, variables $Clim_{it}$ and $Clim_{jt}$ refer to the per-capita level of renewable freshwater resources of country i and j, respectively. They are considered as controls and capture the water scarcity of countries. They are also a way to partially identify the channel by which temperature and precipitation affect the likelihood of signing WTs. A change in the coefficient of these variables (β and μ), once temperature and precipitation are introduced into the estimation, may indicate that our variables of weather and climate change ($Clim_{ijt}$) capture water scarcity.

The term Z_{ijt} refers to a vector of bilateral variables that vary over time, and/or by country and/or by partner. We describe the computation and the source these variables in the Data section.

We believe that fixed effects and controls, as well as the exogeneity of our variable of interest, provide a credible way to interpret the estimate of Equation (2) as a causal relationship. We should however be transparent about the remaining caveats and limitations: first, the control variables that vary at the pair level over time (Z_{ijt}) and that are both exogenous and uncorrelated with our variables of interest are difficult to find (see the data section). Therefore, there is always a possibility that omitted variables influence our results. Second, the advantage of our identification strategy comes at a cost: fixed effects are black boxes that prevent us from analyzing in what economic and political context climate change promotes international water cooperation.[9]

Finally, our estimation relies on a Linear Probability Model (LPM). A well-known issue with LMP is that the estimated coefficients can imply probabilities outside the unit interval (hence we report the % of fitted-values that are inside the interval [0-1]), and so a probit or logit estimation method can be considered as a good alternative approach to estimate Eq. (2). However, given the large number of fixed effects introduced into the model, these estimation methods imply a significant drop in the number of observations (as a consequence of the perfect prediction issue). Put differently, the dependent variable values of the country-pairs which never get involved in a water treaty over the studied period will be fully correlated by the country-pair fixed effects. Accordingly, the LMP is the best available estimation method for our study.

2.4 Data

Our final database covers the period 1961-2007 and is made up of 124 countries.[10] Variables and descriptive statistics are presented in Table 7. The dyad-years is the unit of our analysis.

- *Dependent variable: water treaties (including multilateral treaties) analyzed on a bilateral basis*

The water treaty variable, WT_{ijt}, is a dummy built from the International Freshwater Treaty Database[11] provided by the "Program in Water Conflict Management and Transformation" (College of Earth, Ocean, and Atmospheric Sciences[12]). These treaties are obtained from online databases

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[9] In an online appendix (see Candau and Gbandi 2022), we relax this specification with fixed effects and add political and economic variables (such as the presidential election one year before the signing of a treaty, the common political regime between the partners, past conflicts between the countries, economic interdependence as measured by international trade, etc.).

[10] See Appendix A for the list of countries.

[11] This database has been produced by the Oregon State University, additional information can be found at: <http://www.transboundarywaters.orst.edu>."

[12] Oregon State University

such as the International Water Law Project (FAO database) and the International Environmental Agreements project at University of Oregon. Internet searches for previously identified agreements not included in these databases were also conducted (79 treaties were added in this way). The collection process as well as the time-consuming and arduous task of analyzing the treaties to categorize them has been done "manually" (e.g., following Young (1999)'s categorization concerning the purpose of international environmental treaties), i.e., not by deep learning methods. The method section of Giordano et al. (2013) explains how the treaties were collected and analyzed. Although the researchers who built the Transboundary Freshwater Disputes database translated many treaties into English, the database certainly suffers from attrition bias regarding treaties written in other languages.[13]

This database however contains an impressive number of international, freshwater-related agreements between pairs or groups of countries. These treaties concern "water as a scarce or consumable resource, a quantity to be managed, or an ecosystem to be improved or maintained [...] water rights, water allocations, water pollution, principles for equitably addressing water needs, hydropower/reservoir/flood control development, and environmental issues and the rights of riverine ecological systems".

To build our water treaties variable, we rely on all the international water treaties since 1820 considering countries that are involved in each of them. This database includes both bilateral agreements (when only two countries are engaged in the water treaty) and multilateral agreements (when more than two countries are engaged in a treaty). The fact that we analyzed treaties on a bilateral basis does not mean that we considered only bilateral treaties. All the treaties, including multilateral treaties with many members, were analyzed. Finally, we restricted our database to the years 1961 to 2007, according to the availability of independent variables.

For each multilateral treaty, we generate a set of bilateral combinations of the signatory countries the year when an agreement is signed.[14] Our

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[13] The database is constantly updated and a new database is coming (summer 2023) with more than 100 treaties translated into English.

[14] The number of bilateral combinations per treaty is given by the following combina-

final variable takes a value of one in years when two countries signed a water agreement and zero otherwise. To give some statistics on WTs: there are 622 treaties in the database, 26.30% of the dyads have only one agreement while 62.27% are involved in more than one water agreement (12.43% have no agreement). Many treaties are bilateral (75.72% of them) and one of the largest WTs has 55 members (the African convention on the conservation of nature and natural resources).

It may be noticed that water treaties are often incomplete and based on various specific issues (the classification of water agreements shows that they address thirteen different issues or a mix of them), implying that WTs are often numerous in such a way that a pair of countries can sign several WTs over time. This point was forcefully made by Besedeš et al. (2020) who show that environmental agreements differ from other international agreements such as trade agreements, which are more complete.

The fact that a treaty has been signed on a particular subject does not preclude a new agreement in the future. This may be even more true in the face of rapid climate change, as old water treaties may become obsolete when significant new changes occur. Other factors, such as infrastructure construction, may also require a new treaty (e.g., new dams in an upstream country).

Our final sample is made up of dyads that share at least one water basin.[15] To that end, we use the latest version on shared rivers from the Peace Research Institute Oslo (PRIO)[16]. It specifies whether countries in a dyad share river basin.[17]

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tion (without double counting): $C_n^2 = \frac{(n!)/((n-k)!)}{2}$, with $n \geq 2$ and $k = 2$; n designing the number of countries engage in a cooperation on water resources, and k is the number of countries in a dyad.

[15] Not reported here, we have also estimated our baseline equation by considering a sample where all the possible dyads in each continent were considered (and not just dyads that share a basin). We find similar result with this sample, but further investigations may be interesting in order to better understand how managing freshwater resources may have effects beyond the river/lake basins. As such, a country not close geographically, but indirectly affected by resource depletion, may have an incentive to enter into an agreement.

[16] https://www.prio.org/projects/1291

[17] Indeed, unlike the previous version of PRIO, this newest database accounts for dyads

- *Weather variables*

Variables on temperatures and precipitations are constructed by combining historical monthly weather data (available in raster) provided by Harris et al. (2013) with the river basin's shapefiles from McCracken and Wolf (2019). The historical monthly weather data provide average minimum temperature (°C), average maximum temperature (°C)[18] and total precipitation (mm) with a 2.5-minute (~21 km2) spatial resolution. McCracken and Wolf (2019) also provide the spatial delineations of the international river basins around the world. These river basin delimitations are combined with the world country boundaries shapefile to obtain, for each country, its river basin coverage area. Thus, by merging these country river basin coverage area shapefiles with the historical monthly weather data, we are able to extract, with Geographic Information System Mapping's tools, for each country, average temperatures and precipitations all along areas of land that drain waters to their common terminus (ocean, sea, or terminal inland water body). We compute temperatures and precipitation at the river basin level in each country, rather than over the whole country's surface, because we expect them to be more correlated with river flows.[19]

With these data at hand, we generate the mean temperature and mean precipitation by pair of countries. Two other variables are derived from the aforementioned weather indicators for robustness checks. First, we consider for each dyad the temperature (and precipitation) of the country which has the highest temperature (and precipitation) variability over the studied period (we use the coefficients of variation, hereafter denoted CV). Second, temperature and precipitation measures are used to compute the number of hottest and rainiest months for every year. These variables

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that share river basin without sharing a border.

[18] A mean temperature is generated with these maximum and the minimum temperatures.

[19] These regions are often specialized in agriculture and/or are the location of large cities. Therefore, in these regions flooding or drought often have serious consequences that are also largely mediatized at the national level. Weather fluctuations in these regions can thus have political implication at the national level. We also rely on climate variables built on the countries' total surface as robustness checks.

are obtained by counting the number of months during which country-basins experienced temperatures (and precipitation) above the decade's mean level temperatures (and precipitations). Next, averages are computed for the dyads.

Furthermore, we account for weather shocks by relying on drought and flood events. Because an isolated event in a given year may not be sufficient to trigger incentives for countries to cooperate over water resources, we calculate the yearly cumulative number of each of these two events (drought and flooding) at the country level since the year 1950. In doing so, we test whether the likelihood of cooperating over water resources depends on the frequency of drought and flooding events. Further, we generate and use the dyadic mean of these variables. Data on floods or droughts come from the Centre for Research on the Epidemiology of Disasters[20].

The renewable internal freshwater resources per capita (cubic meters) variable is from the Food and Agriculture Organization (AQUASTAT data). This indicator refers to the average annual flow of rivers to groundwater generated from precipitation. Because these datasets comprise a lot of missing values, we compute for every country a five-year average value. The number of joint international organizations to which states in each dyad are affiliated comes from the third version of the Correlates of War IGO datasets.

It is worth noting that, instead of relying on contemporaneous explanatory variables, we lag them by one year to account for the fact that water treaties signed at the beginning of a given year are likely to be the result of climate shocks in the preceding year. Supplementary analyses that account for the accumulation of temperature and precipitation shocks are also proposed for robustness checks.

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[20] Available on request at https://www.emdat.be/

3 Short-run results

3.1 Weather fluctuations and treaties

In Table (1, Column 1), we introduce the indicator of water scarcity, namely the level of renewable freshwater resources at the country level (referenced as $Clim_{it}$ and $Clim_{jt}$ in Equation,2), without any control. In line with the literature, we find that the availability of freshwater is negatively correlated with the signing of WTs. In Column 2, we consider the effect of the average temperature and precipitation in countries i and j. These two variables defined at the basin level of countries i and j, namely $Clim_{ijt}$ in Equation (2), are our main variables of interest. We find that an increase in temperature significantly explains the likelihood of signing a WT.[21] Consistent with the idea that water scarcity influences treaty signature, a decrease in precipitation leads to a higher probability of WT. In Column 3, all the variables of Column 1 and 2 are simultaneously introduced. Interestingly, the renewable freshwater variables are now unsignificant. We may interpret this result as an indication that precipitation and temperature variables capture the impact of water scarcity on treaties. In Column 4, we introduce year fixed effects, income-group time-varying effects and continental time-effects. The previous results are all verified.

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[21] Though not reported here, we also verify that these variables still have a similar effect when taken separately (for instance, the coefficient of temperature in country i equals 0.0099 (significant at 5%) and that of precipitation in i equals -0.023, also significant at 5%).

Table 1: Correlations between Water Treaties, Water Scarcity, Temperature and Precipitation

	(1)	(2)	(3)	(4)
Avg Temp ($Clim_{ijt}$)		0.0019^{a}	0.0019^{a}	0.0014^{c}
		(0.0003)	(0.0003)	(0.0008)
Avg Prec ij ($Clim_{ijt}$)		-0.0023^{a}	-0.0027^{a}	-0.0042^{a}
		(0.0004)	(0.0007)	(0.0011)
Renew freshwater in i ($Clim_{it}$)	-0.0005^{c}		0.0028	0.0032
	(0.0003)		(0.0018)	(0.0026)
Renew freshwater j ($Clim_{jt}$)	-0.0047^{a}		-0.001	0.0013
	(0.0013)		(0.0016)	(0.002)
Common inter organizations				0.0006^{a}
				(0.0002)
Constant	0.0914^{a}	0.0429^{a}	0.030^{c}	0.008
	(0.0118)	(0.0052)	(0.0172)	(0.0256)
Observations	11868	11868	11868	11868
% fitted values ϵ [0; 1]	100.00	100.00	99.74	99.71
R-squared	0.001	0.005	0.005	0.444

Notes: Standard errors adjusted for clustering at the country pair level. a: p<0.01, b: p<0.05, c: p<0.1. The dependent variable is a dummy taking one when countries *i* and *j* have signed a river treaty at time *t*. This dummy is built from the International Freshwater Treaty Database. We use an LPM estimator over the period 1961-2007. In Columns 1, 2 and 3 there are no fixed effects. In Column 4 the regression include year fixed effects, income-group time-varying effects, and continental time-varying effects.

In Table 2 we estimate Equation (2), with all the controls of the previous Table (3, Column 4) and with bilateral fixed effects. The difference between each estimation/column lies in the weather variables, $Clim_{ijt}$: temperature and precipitation in Column 1, temperature and precipitation based on the highest variation of these variables between partners in Column 2, the number of rainiest and hottest months in Column 3 and the number of flood and drought events in Column 4.

The point estimate of α indicates that, *ceteris paribus*, a one-degree Celsius increase in temperature has led to a 2.11% increase in the likelihood of signing WTs. Similarly, a decrease in precipitation by one unit (mm/m^2) has caused a 0.48% increase in the signing of WTs. Because these estimates of α are based on a year-on-year analysis, we consider that they provide results relating to the short-run effects of temperatures and precipitation. However, since the time period is from 1961 to 2007, we expect this period to be long enough to extrapolate the fact that climate change (and not just weather fluctuations) is accounted for by this analysis, at least in the sign of α (the magnitude of this coefficient certainly underestimates the effect of climate change. We come back to this point in the last section of this article). As already mentioned, individuals often consider weather fluctuation as an indication of climate change (Sambrook et al., 2021).

In Column 2, we change our vector of variables $Clim_{ijt}$ by considering the highest temperatures and precipitation out of the pair. These variables have the advantage of capturing partially how weather anomalies, such as large shocks in one country, affect WTs. We find that the highest level of precipitation as well as the highest level of temperatures determine the likelihood of signing an agreement. Precipitation has a negative effect and temperature a positive one.

In Column 3, weather conditions $Clim_{ijt}$ are approximated by the number of warm and rainy months, which enables us to confirm the results presented so far. In Column 4 we find that the cumulative numbers of months with flood events decrease the likelihood of signing water treaties.

Variables of control that vary at the country level, $Clim_{it}$ and $Clim_{jt}$, approximated by the level of renewable freshwater resources are no longer significant, as already observed in Table 1.

Finally, the number of international organizations that are common to the two partners, which is considered as a proxy of integration or cooperation between signatories, is not significant.

Table 2: Water Treaties and Climate Change in the Short Run - Baseline results

	1:	Avg Temp	Temp high CV	Warm months	Drought
	2:	Avg Prec	Precip high CV	Rainy months	Flooding
Weather variable 1		0.0211^{a}	0.0098^{c}	0.0679^{b}	0.0010^{c}
		(0.0057)	(0.0054)	(0.0295)	(0.0009)
Weather variable 2		-0.0048^{b}	-0.0035^{b}	-0.0790^{a}	-0.0017^{a}
		(0.0024)	(0.0017)	(0.0227)	(0.0005)
Renew freshwater in i ($Clim_{it}$)		-0.0071	-0.0067	-0.0065	-0.0090
		(0.0170)	(0.0171)	(0.0172)	(0.0172)
Renew freshwater j ($Clim_{jt}$)		0.0009	0.0013	0.0027	-0.0057
		(0.0162)	(0.0162)	(0.0164)	(0.0162)
Common inter organizations		0.0001	0.0001	0.0001	0.0001
		(0.0003)	(0.0003)	(0.0003)	(0.0003)
Constant		-0.2302	-0.0375	0.0835	0.1889
		(0.2339)	(0.2262)	(0.1967)	(0.1964)
Observations		11,868	11,868	11,868	11,868
% fitted values ϵ [0; 1]		63.89	67.31	99.99	96.00
R-squared		0.473	0.472	0.473	0.473

Notes: Standard errors adjusted for clustering at the country pair level. a: $p<0.01$, b: $p<0.05$, c: $p<0.1$. The dependent variable is a dummy taking one when countries i and j have signed a river treaty at time t. This dummy is built from the International Freshwater Treaty Database. Weather variables 1 and 2 are reported in each column: in Column 1, it is respectively the average temperature and precipitation, in Column 2, the highest temperature and precipitation of the pair, and so on. Climate variables comes from WorldClim. We use a LPM estimator over the period 1961-2007. All the regressions include the following effects: year fixed effects, income-group time-varying effects, continental time-varying effects, and bilateral fixed effects.

It is worth arguing that by lagging our explanatory variables to one year (which leaves time for water treaties to be formed in response to climate shocks), we oversimplify the motivation of countries to enter into a WT. Repeated temperature and precipitation shocks certainly have a different effect on the likelihood of signing WTs. While we analyze this question over a long-term period in Section 4, we extend our analysis slightly in Appendix C by relying on temperature and precipitation shocks over a medium-term period, i.e., the two years preceding the treaties. Results show that temperature shocks over the two years preceding the WTs increase the likelihood of entering into a WT, while joint precipitation shocks during this time period reduce this probability. In sum, these results confirm our baseline results reported in Table 2 and also indicate that repeated shocks may have a stronger effect (coefficients are higher with this lag of two years).

In Appendix D, we analyze a different question by asking where a change in temperature/precipitation has the biggest impact on the likelihood of signing a treaty: in the downstream country or in the upstream one? We do not find a definitive answer, as temperature and precipitation matter in upstream countries while only precipitation is significant for downstream countries.[22]

3.2 Complementary results

Weak and strong treaties

The previous analysis shows that temperature and precipitation lead to an increase in the signature of WTs, but which kinds of WTs? Indeed, as we emphasized in the first section, WTs have different contents; some are strong treaties while other are weak and then the likelihood of their implementation is low. Here we aim to analyze whether a change in weather conditions leads to strong treaties or whether they are merely political "green washing".[23]

To analyze this, we use the International Freshwater Treaty Database, which provides two indications on agreements to distinguish strong from weak treaties. We consider strong treaties as those that "*oblige the parties to adopt national laws or develop national programs in order to meet treaty provisions*" and also treaties in which the "*document contains provisions concerned with the enforcement of the provisions of the document*". All other agreements are considered as weak treaties.

The first interesting result, reported in Table 3, is that temperature has a positive effect on both types of treaties. This is not the case for precipitation, which is only significant for weak treaties; however, the negative sign for renewable freshwater (albeit only significant for one country and at a 10% level only) indicates that water scarcity may also be relevant to

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[22] In an online Appendix (see Candau and Gbandi, 2022), we also analyze to what extent these weather variables have a non-linear effect on the signature of WTs.

[23] See for instance Battaglini and Harstad (2020) who propose a model explaining under which conditions strong or weak treaties are negotiated. They assume that politicians focus on their probability to be elected (or re-elected) and then chose strategically the content of international treaties to win votes accordingly.

the signing of strong treaties.

Table 3: Weak and Strong Water Treaties

	Weak	Strong	Small	Medium	Large
Avg Temp (ij)	0.0110^{b}	0.0101^{a}	0.0208^{a}	0.0211^{a}	-0.0022
	(0.0049)	(0.0035)	(0.0055)	(0.0057)	(0.0031)
Avg Prec (ij)	-0.0064^{a}	0.0015	-0.0016	-0.0048^{b}	-0.0010
	(0.0022)	(0.0014)	(0.0023)	(0.0024)	(0.0008)
Renew freshwater in i ($Clim_{it}$)	-0.0018	-0.0053	0.0093	-0.0071	-0.0099
	(0.0141)	(0.0063)	(0.0136)	(0.0170)	(0.0077)
Renew freshwater j ($Clim_{jt}$)	0.0120	-0.0111^{c}	0.0071	0.0009	-0.0058
	(0.0139)	(0.0062)	(0.0128)	(0.0162)	(0.0079)
Common international organizations	0.0007^{a}	-0.0005^{a}	-0.0001	0.0001	0.0000
	(0.0002)	(0.0001)	(0.0003)	(0.0003)	(0.0001)
Constant	-0.2005	-0.0297	-0.4520^{b}	-0.2302	0.1936^{c}
	(0.1962)	(0.0884)	(0.2074)	(0.2339)	(0.1002)
Observations	11,868	11,868	11,868	11,868	11,868
% fitted values ϵ [0; 1]	68.12	59.57	59.91	63.89	71.71
R-squared	0.508	0.155	0.237	0.473	0.681

Notes: Standard errors adjusted for clustering at the country pair level. a: p<0.01, b: p<0.05, c: p<0.1. The dependent variable is a dummy taking one when countries *i* and *j* have signed a river treaty at time *t*. This dummy is built from the International Freshwater Treaty Database. Climate variables comes from WorldClim. We use a Fixed Effect model over the period 1961-2007. All the regressions include the following effects: year fixed effects, income-group time-varying effects, continental time-varying effects and bilateral fixed effects.

Our way to discriminate between weak and strong treaties differs from the literature on environmental agreements. For instance, Besedeš et al. (2020) consider that strong treaties will have fewer signatories as those agreements are more easily enforced and as such are more likely to deal with common pool resources, such as freshwater, since common pool resources are more likely to be shared by a small number of countries. Besedeš et al. (2020) refer to large treaties as treaties of statement or desire to address an issue, but they ultimately do little given the coordination issues with a large number of signatories. Thus, large treaties for them are weak treaties. This definition of weak/strong treaties based on the number of participants has been supported by various theoretical findings since the seminal work of Barrett (1994). We then re-estimate Equation (2) by considering treaties with fewer than 10 members (Column 3), with more than 10 but fewer than 20 signatories (Column 4) and finally large treaties with more than 20 signatories (Column 5). Temperatures are significant for small and medium size treaties, and precipitation is significant for treaties with an intermediate number of countries. These two indicators are not significant for treaties with a large number of members. Then, from this definition of the weakness of treaties, we may conclude that temperatures and precipitation have no impact on the likelihood of signing weak treaty but are more efficient in triggering strong treaties (temperatures matter in particular).[24]

How does the EU influence these results?

In the European Union, the presence of a supranational authority that is in tasked with taking into account the externality of climate change and then fostering the harmonization of norms on water, may lead to stronger treaties between members of the Union than in other parts of the world. As stated in the first section, the European Union is one of the most advanced regions in term of water protection. This may bias our main results, especially according to the bilateralization of treaties: given the definition of observations based on country pairs, a multilateral treaty increases the dependent variable exponentially in the number of signatories. To be sure that these European multiparty treaties do not absorb the effects in the years they are signed, we propose to re-run the analysis excluding Europe. Indeed, Europe is characterized by several multi-party treaties and may thus drive the results obtained, as a few river basins in Europe span numerous geographically small countries. In Column 1, we adopt a broad rule of exclusion by dropping all European countries (for the whole period).[25] Then in Column 2 we exclude countries (i *or* j) when they enter the European Union, and finally in Column 3 we exclude, on a year basis, the pair of countries (i *and* j) that are in the European Union.

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[24] We have carried out several other estimations not reported here. For instance, by considering treaties with fewer than thirty signatories, we find that temperature and precipitation are significant, while this result does not hold for a number of members above this threshold.

[25] More precisely we exclude: Albania; Austria; Belgium; Bosnia and Herzegovina; Bulgaria; Croatia; Denmark; Estonia; Finland; France; Germany; Greece; Hungary; Italy; Latvia; Lithuania; Luxembourg; Netherlands; Norway; Poland; Portugal; Republic of Moldova; Slovakia; Slovenia; Spain; Sweden; Switzerland; Ukraine.

Table 4: Without Europe

	(1)	(2)	(3)
	EU countries excluded [Entry date in EU not considered]	Excluded if *i* is EU or *j* is EU [Entry date in EU considered]	Excluded if *i* is EU and *j* is EU [Entry date in EU considered]
Avg Temp (ij)	0.0266^a	0.0182^a	0.0205^a
	(0.0069)	(0.0064)	(0.0062)
Avg Prec (ij)	-0.0044^c	-0.0051^b	-0.0054^b
	(0.0025)	(0.0023)	(0.0023)
Renew freshwater in i ($Clim_{it}$)	-0.0106	-0.0101	-0.0098
	(0.0168)	(0.0169)	(0.0169)
Renew freshwater j ($Clim_{jt}$)	0.0172	0.0146	0.0094
	(0.0166)	(0.0160)	(0.0159)
Common international organizations	0.0004	0.0006*	0.0004
	(0.0004)	(0.0003)	(0.0003)
Constant	-0.5223^b	-0.2994	-0.2785
	(0.2376)	(0.2313)	(0.2288)
Observations	9,016	10,502	11,323
% fitted values ϵ [0; 1]	75.64	70.29	66.07
R-squared	0.493	0.502	0.494

Notes: Standard errors adjusted for clustering at the country pair level. a: p<0.01, b: p<0.05, c: p<0.1. The dependent variable is a dummy taking one when countries *i* and *j* have signed a river treaty at time *t*. This dummy is built from the International Freshwater Treaty Database. Climate variables comes from WorldClim. We use a Fixed Effect model over the period 1961-2007. All the regressions include the following effects: year fixed effects, income-group time-varying effects continental time-varying effects and bilateral fixed effects.

The results are very similar between the different columns presented here and also quite close to those obtained previously, indicating that European countries do not introduce a sampling bias. By comparing the first column with the result of our baseline (Table 2), the coefficient is slightly higher (an elasticity of 26% instead of 21% for temperatures), which might indicate that the relationship between temperatures and the probability of signing a treaty is stronger in the rest of the world. Finally, the fact that the coefficients are higher in this first column (where the rule of exclusion is based on European countries) than in other columns where entry into the European Union has been chosen (in which case the coefficients are very close to the baseline, for instance 20,5% for temperatures in Column 3) may indicate that it is not membership of the EU that matters. Relatively well-functioning insurance markets and/or strong welfare states in case of catastrophic events in Europe may explain why the response of WTs to weather fluctuations are smaller when these countries are included in the analysis.

4 Water treaties and climate change in the long run

4.1 Different time, different behavior?

The estimation of Equation (2) enables us to present the short-run effects of several determinants of transboundary water treaties. This empirical strategy is valid as long as the periods before and after the climate shock are small enough. Consequently, the empirical strategy developed until now focuses on the short-run effect of climate change by considering fluctuations on an annual basis. But if governments can adjust their policy in the long run in ways that are not controlled then our results may underestimate the long-run effects of climate change. For instance, political tensions in a drought year might be overcome in the long run by a common investment in the management of the resource.

The issue of why politicians sign more WTs in the long run is complex and multifaceted, and the micro-foundations of these decision-making process remain elusive due to the heterogeneity of political governance structures involved. However, it appears plausible to suggest that, in general, the political class has gradually internalized the impact of climate shocks over the course of several decades, leading to the utilization of WTs as a means of demonstrating their commitment to safeguarding the well-being of their constituents through international negotiations.

To analyze this hypothesis, we implement the "long differences" methodology proposed by Burke and Emerick (2016). More precisely, we estimate the effect of climate change on WTs by relying on the following equation:

$$\begin{aligned}\overline{WT_{ijt_2}} - \overline{WT_{ijt_1}} = \alpha(\overline{Clim_{ijt_2}} - \overline{Clim_{ijt_1}}) + \beta(\overline{Clim_{it_2}} - \overline{Clim_{it_1}}) \\ + \mu(\overline{Clim_{jt_2}} - \overline{Clim_{jt_1}}) + \Delta\varepsilon_{ij}\end{aligned} \tag{3}$$

where $\overline{WT_{ijt_2}}$ and $\overline{WT_{ijt_1}}$represent the average number of water treaties signed during two periods.[26] We first present the general results of $\widehat{\alpha}$ for temperature and precipitation on a decadal basis, then in the next subsections we present a particular period to detail our results for different type of treaties.

What we expect is an increasing positive impact of temperature and a negative one for precipitation. Results are presented for these two variables in Figure 4.1.a and 4.1.b. The first estimation of Equation (3) is done with $t_1 = [1961, 1970]$ and $t_2 = [1971, 1980]$ (depicted in blue), then we extend the long difference by considering the next decade, $t_2 = [1981, 1990]$ in our second estimation (in red), in the third one we take $t_2 = [1991, 2000]$ (in green) and in the last estimation we use the last seven years of our sample $t_2 = [2001, 2007]$ (in yellow).

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[26] It is worth noting that this approach serves to overcome the limitations of cross-sectional approaches. Indeed, in comparison with the literature where the averages of different variables are taken over a long period of time with the risk of bias due to omitted variables, here the estimates are immune to time-invariant omitted variables by long differentiating. Furthermore, in comparison with the FE model presented in (2), coefficients α, β and μ are estimated from long-term changes in average conditions instead of year-on-year changes and can thus be used to take into account the adaptation of governments to signing WTs.

At the start of the period (blue estimates), precipitation is not significant and the effect of temperature is even negative. The second long difference (in red) shows that an increase in temperature starts to positively influence the likelihood to sign WTs, the effect is however weak and precipitation are still unsignificant. These results are in line with what we know, the period 1961-1974 was a period of relative indifference about climate change. For instance, the Club of Rome's report on "The Limit to Growth" published in 1972 (Meadows et al., 1972), was largely criticized at that time and then ignored (see Simmons, 2000). In the aftermath of the oil crisis, attitudes began to change slowly, but knowledge about the consequences of climate change was still largely confined to academic research circles. Things really started to change in the 1990s. In 1993, for the first time, the United Nations Framework Convention on Climate Change established an international environmental treaty to combat "dangerous human interference with the climate system", ratified by 50 countries. This treaty came into effect in 1994 and was then extended under the so-called *Kyoto Protocol* in 1997. One year later, the "Hockey-Stick" of the dentrochronologists Mann et al. (1998) became famous[27] by showing that the hottest year, in their sample of 1000 years, was 1998 (the latest year of their record). This result was at the heart and soul of the 2001 report of the Intergovernmental Panel on Climate Change (IPCC) that won the 2007 Nobel Peace Prize for its recognition of climate change.

This is verified for WTs as illustrated by our third estimation (in green, with $t_2 = [1991, 2000]$), both temperature and precipitation are now significant. Our last period is shorter than the previous one, but still confirms these results. This does not mean that during the period 1960-1990, individuals and governments did not face the effects of global warming (which concerned all of the twentieth century), but it was certainly difficult to discern long-term climate change from the notorious variability of local weather. In contrast, the repetitive "loading of the climate dice" describing the increase in the probability of unusually warm or cool seasons (Hansen et al., 2012), decade after decade, may have led all stakeholders to adapt their behaviors.

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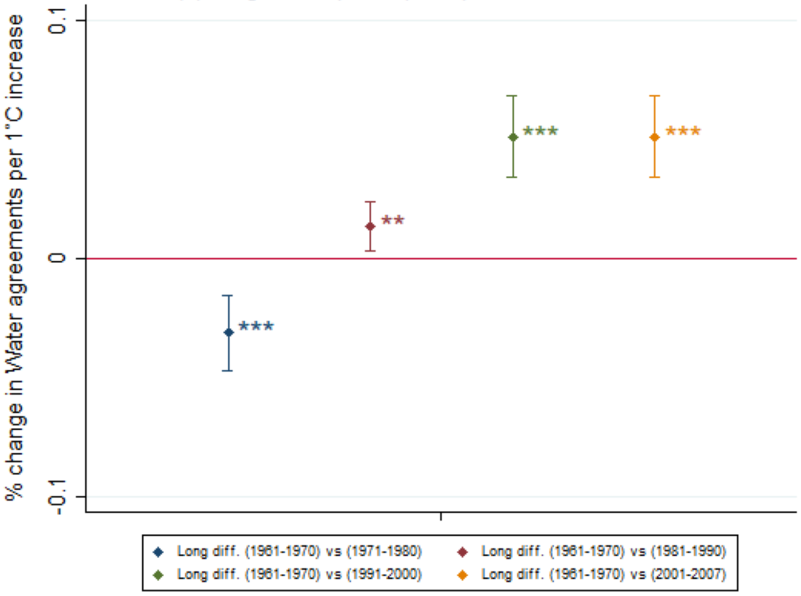
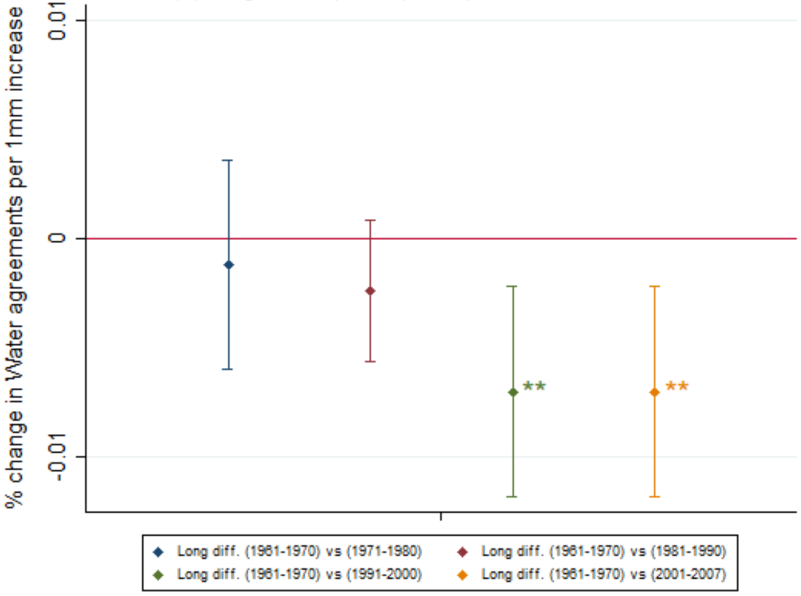
[27] See for instance the *New York Times* article of Stevens (1998).

Figure 2: Long-run response from a decadal analysis

(a) Long-run response | Temperature effect over time



(b) Long-run response | Precipitations effect over time



Notes: Water treaties are computed bilaterally and comes the International Freshwater Treaty Database. Average temperature and precipitations are computed at the river basin level of countries.

4.2 Water Treaty, an international adaptation strategy

In Table (5, Column 1), we present the results from the long differences estimates following the specification in Equation (3) for the periods $t_1 = [1961, 1975]$ and $t_2 = [1993, 2007]$. As explained and shown in the previous section, these two periods display a significant change in the relationship between climate change and the signing of treaties. All the results presented in the previous sections are verified. Changes in climatic conditions observed between 1961-75 and 1993-2007 have a determining effect on the probability of signing WTs. International cooperation on common basins seems to be a function, not solely of weather fluctuations, but of the awareness of climate change observed during the long period considered. Moreover, coefficients are much higher than those presented in Table 2, indicating that our short-run analysis underestimated the effect of climate change. Indeed, we find here that a one-degree Celsius increase in temperature has resulted in a 16.6% increase in the likelihood of signing WTs over the period considered. Similarly, a decrease in precipitation by one unit (mm/m^2) has caused a 3% increase in the signing of WTs.

In Columns 2 and 3, we analyze the effect of temperature and precipitation on the "nature" of treaties, by categorizing them into weak and strong treaties. As in the short run, temperature positively influences both types of treaties. Precipitation no longer matters but renewable freshwater becomes significant in that case. These results indicate that water scarcity also influences the signing of strong treaties.

Table 5: Long Difference: Climate Change Really Matters

	All	Weak	Strong
Avg Temp (ij)	0.1660^a	0.0928^a	0.0731^a
	(0.0358)	(0.0292)	(0.0143)
Avg Prec (ij)	-0.0306^c	-0.0248^c	-0.0058
	(0.0178)	(0.0147)	(0.0067)
Renew freshwater in i ($Clim_i$)	-0.0367	0.0295	-0.0662
	(0.2997)	(0.2412)	(0.1470)
Renew freshwater j ($Clim_j$)	-0.2721	-0.0969	-0.1753^b
	(0.1767)	(0.1242)	(0.0748)
Common international organizations	-0.0002	0.0008	-0.0011^a
	(0.0006)	(0.0005)	(0.0002)
Constant	-0.1739^b	-0.1633^a	-0.0105
	(0.0722)	(0.0610)	(0.0210)
Observations	258	258	258
R-squared	0.227	0.287	0.291

Notes: Standard errors adjusted for clustering at the country pair level. a: p<0.01, b: p<0.05, c: p<0.1. The model estimates water treaties in long differentiating variables between 1961-75 and 1993-2007. Data on water treaties comes from the International Freshwater Treaty Database. Climate variables comes from WorldClim.

To conclude, the likelihood of governments of signing international river treaties due to climate change is higher in the long run. The most natural explanation of this result is that the environmental consequences of climate change have grown over time, leading governments to sign new WTs with environmental purposes (as discussed in the introduction). A corollary of this proposition is that past treaties, even those with environmental purposes or development objectives, may have failed to resolve problems linked to climate change in the short run, leading the signing of WTs in the long run. This last argument is based on the hypothesis that past water treaties have been inefficient in resolving the ongoing climate crisis. To test this, we estimated our baseline equation with the cumulative number of treaties as a dependent variable. If past treaties were inefficient, then we may observe an increase in this cumulative number faced with climate change. We do not observe this, temperatures for instance are not significant in this case. We do not report these results here to save space, but they may be worth mentioning for future research.

4.3 Does the Content of Treaties Matter?

As already discussed, WTs are heterogeneous in their contents, and our previous analysis that considers strong and weak treaties refers to only one dimension of this heterogeneity. For instance treaties on economic development may be influenced very differently by climate change to treaties that address environmental issues.[28] Therefore, we propose to re-estimate Equations (2) and (3) by distinguishing different types of treaties, namely treaties on "Water quantity and Water quality issues", "Economic development" and "Environmental services or protection".[29]

Table 6 reports the short-run effect and the long difference reaction in terms of these aforementioned types of agreements to climate shocks. We present results relative to dyadic average temperatures and average precipitation only, but similar results are obtained for all other climate variables.

We find that temperature almost always has a significant effect, the sole exception being for water quantity and quality, but only in the short run. The impact of precipitation is significant and negative on economic development and environmental protection in the long run. In conclusion, temperature and, to a lesser extent, precipitation, have a significant effect on the probability of signing a wide variety of treaties. This is perhaps unsurprising since global warming has a widespread effect on water quantity/quality, economic development and environmental protection projects.

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[28] The distinction between the content (development or environmental issues) and the nature (weak or strong) of treaties may, however, be related. For instance, Battaglini and Harstad (2020) argue that weak treaties are more numerous when they concern environmental issues than when they are related to security issues.

[29] To select these contents, we use the "Issue Area" column of the International Freshwater Treaty Database that identifies, in the text of the treaty, the main issue area of the document. Since more than one issue area can be listed, we focus on treaties that are exclusively on "Water quantity and Water quality issues", "Economic development" and "Environmental services or protection".

Table 6: Climates related reasons for water agreements: sensitivity analyses

	(1)	(2)	(3)	(4)	(5)	(6)
	Likelihood of water agreements					
	Short run results			Long differences results		
	Water quantity & Water quality	Economic development	Environment protection	Water quantity & Water quality	Economic development	Environment protection
Avg Temp (ij)	0.0081	0.0114^a	0.0148^a	0.0533^b	0.0622^a	0.0477^b
	(0.0052)	(0.0034)	(0.0047)	(0.0237)	(0.0170)	(0.0205)
Avg Prec (ij)	0.0012	-0.0027^b	-0.0008	0.0019	-0.0197^b	-0.0222^b
	(0.0020)	(0.0011)	(0.0014)	(0.0112)	(0.0090)	(0.0106)
Renew freshwater in i ($Clim_{it}$)	-0.0008	-0.0115	-0.0076	-0.4079^b	0.3591^b	0.3249^c
	(0.0121)	(0.0071)	(0.0072)	(0.1777)	(0.1465)	(0.1752)
Renew freshwater j ($Clim_{jt}$)	-0.0047	0.0027	-0.0010	-0.0694	-0.1311^c	-0.0625
	(0.0116)	(0.0064)	(0.0071)	(0.1135)	(0.0741)	(0.0637)
Common International Organizations	-0.0003	0.0001	-0.0003	-0.0005	-0.0000	-0.0006^c
	(0.0002)	(0.0001)	(0.0002)	(0.0005)	(0.0002)	(0.0003)
Constant	-0.0550	-0.0906	-0.1552	-0.0395	0.0477^c	-0.0018
	(0.1790)	(0.0987)	(0.1315)	(0.0426)	(0.0250)	(0.0343)
Observations	11,868	11,868	11,868	258	258	258
% fitted values ϵ [0; 1]	66.55	62.07	60.98			
R-squared	0.576	0.568	0.174	0.186	0.435	0.175

Notes: Standard errors adjusted for clustering at the country pair level. a: p<0.01, b: p<0.05. The short run results in Column 1, 2 and 3 are obtained by estimating water treaties with a Fixed Effect model (including the following effects: year fixed effects, income-group time-varying effects, continental time-varying effects and bilateral fixed effects). The long differences results in Column 4, 5 and 6 are obtained by estimating water treaties in difference between 1961-70 and 1998-2007. Data on water treaties comes from the International Freshwater Treaty Database. Climate variables comes from WorldClim.

5 Conclusion

The recent report from the Intergovernmental Panel on Climate Change (IPCC, 2022) underscored once again the current climate crisis and called for urgent action and an end to "dithering" by politicians. The inaction of governments is indeed a fact in various environmental issues, in particular greenhouse gas emissions. In this paper, we aim to analyze whether such a conclusion is verified for transboundary waters. Governments have long since signed several water treaties on common basins, but the motives behind these agreements are not yet fully understood. The literature has emphasized that these agreements have been signed to prevent conflicts, or, conversely, that the hegemony of some countries has led them to legally exploit transboundary waters. However, to date, the effect of climate change has remained an open question. We present the first study to show that an increase in temperatures and a decrease in precipitation lead to the signing of WTs. Such a result is verified for strong treaties as well as for treaties with different contents (related to economic development and environmental protection). Our results also show that WTs are adaptation policies, in the sense that long-run differences in climate variables foster the likelihood of signing WTs. Obviously, the effectiveness of these international agreements remains unknown, and the increasing number of these treaties might reflect the fact that solutions to preserve common basins are hard to find. More research is needed to analyze how governments effectively cooperate to cope with the forthcoming increase in stress on water resources due to global warming. More data on WTs is needed to better analyze their ambitions and under which conditions these treaties are actually implemented. One possibility not explored so far for WTs, but already investigated for the Paris Agreement on climate change (Victor et al., 2022), could be to survey experts and negotiators of WTs in order to better analyze the credibility of these treaties. In addition, to assess the effectiveness of these agreements, ecological indicators at the basin level may also be useful. For example, indicators of transboundary ecosystem services could be constructed along shared basins to study the impact of WTs on these dimensions. To conclude, at a time when agreements to preserve the atmosphere are urgently needed, we can learn a lot from agreements on water, which, as we have shown, have a relatively long history related to climate change.

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Appendix A: list of countries

The current study is based on a sample of countries that includes: Afghanistan; Albania; Algeria; Angola; Argentina; Armenia; Austria; Azerbaijan; Bangladesh; Belgium; Belize; Benin; Bhutan; Bosnia and Herzegovina; Botswana; Brazil; Bulgaria; Burkina Faso; Burundi; Cambodia; Cameroon; Canada; Central African Republic; Chad; Chile; China; Colombia; Congo; Costa Rica; Croatia; Denmark; Djibouti; Dominican Republic; Ecuador; Egypt; El Salvador; Equatorial Guinea; Eritrea; Estonia; Ethiopia; Finland; France; Gabon; Gambia; Georgia; Germany; Ghana; Greece; Guatemala; Guinea; Guinea-Bissau; Guyana; Haiti; Honduras; Hungary; India; Indonesia; Iran (Islamic Republic of); Iraq; Israel; Italy; Jordan; Kazakhstan; Kenya; Kyrgyzstan; People's Democratic Republic; Latvia; Lebanon; Lesotho; Liberia; Libya; Lithuania; Luxembourg; Malawi; Malaysia; Mali; Mauritania; Mexico; Mongolia; Morocco; Mozambique; Myanmar; Namibia; Nepal; Netherlands; Nicaragua; Niger; Nigeria; Norway; Pakistan; Panama; Paraguay; Peru; Poland; Portugal; Republic of Korea; Republic of Moldova; Rwanda; Senegal; Sierra Leone; Slovakia; Slovenia; Somalia; South Africa; Spain; Sudan; Suriname; Sweden; Switzerland; Syrian Arab Republic; Tajikistan; Thailand; Togo; Tunisia; Turkey; Turkmenistan; Uganda; Ukraine; United Republic of Tanzania; United States of America; Uruguay; Uzbekistan; Zambia; Zimbabwe.

Appendix B: Descriptive statistics

Table 7: Descriptive statistics

Variables	Obs	Mean	Std. Dev.	Min	Max
	Bilateral level				
Bilateral water agreements (all)	11,868	.057	.233	0	1
Weak treaties	11,868	.049	.216	0	1
Strong treaties	11,868	.008	.092	0	1
Water quantity & quality treaties	11,868	.041	.198	0	1
Economic development treaties	11,868	.019	.138	0	1
Environment protection treaties	11,868	.018	.134	0	1
Avg Temperature	11,868	17.65	7.740	-1.05	29.8
Avg Precipitations	11,868	7.89	4.826	.392	36.1
Avg Number of warmer months	11,868	.526	.090	0	12
Avg Number of rainier months	11,868	.433	.091	1.5	11
Avg yearly cumulative number of drought events	11,868	5.06	7.13	0	43
Avg yearly cumulative number of flood events	11,868	9.53	12.39	0	88
Renewable internal freshwater resources per capita (cubic meters)	11,868	8.31	1.64	3.13	12.89
Number of common International Governmental Organizations	11,868	32.10	22.61	0	101
	Unilateral/Country level				
Avg Temperature	4,416	16.59	8.53	-1.44	30.39
Avg Precipitations	4,416	8.84	5.502	.059	37.61
Number of warmer months	4,416	.522	.108	0	12
Number of rainier months	4,416	.431	**.116**	0	11
Yearly cumulative number of drought events	4,416	2.18	3.82	0	25
Yearly cumulative number of flood events	4,416	4.28	6.52	0	49
Renewable internal freshwater resources per capita (cubic meters)	4,416	8.67	1.83	3.13	12.9

Appendix C: two lags

In this appendix we analyze temperature and precipitations shocks over two years. The join effects over these periods are obtained by summing up the coefficients on the lags over the periods. The join coefficients and their standard errors and significance levels are computed using on the "Delta method”.[30] We find that temperature shocks during the two years preceding the WTs increase the likelihood to enter a WT while the join precipitations’ shocks during this time periods reduce this probability.

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[30] See the Stata command “nlcom”.

Table 8: Water Treaties and Climate Change in the Short Run - Repeated shocks analyses

	(1)
	Likelihood of water agreements
Avg Temp in i and j (1 year-lag)	0.0167^{a}
	(0.0060)
Avg Temp in i and j (2 year-lag)	0.0356^{a}
	(0.0077)
Avg Prec in i and j (1 year-lag)	-0.0059^{b}
	(0.0026)
Avg Prec in i and j (2 year-lag)	-0.0019
	(0.0023)
Renew freshwater in i ($Clim_{it}$)	-0.0061
	(0.0185)
Renew freshwater j ($Clim_{jt}$)	0.0001
	(0.0176)
Common inter organizations	0.0002
	(0.0003)
Constant	-0.7562^{a}
	(0.2516)
Join temperature effect over the period	0.0522^{a}
	(0.0082)
Join precipitations effect over the period	-0.0078^{b}
	(0.0033)
Observations	11,610
% fitted values ϵ [0; 1]	60.39
R-squared	0.474

Notes: Standard errors adjusted for clustering at the country pair level. a: p<0.01, b: p<0.05. The dep variable is a dummy taking one when countries *i* and *j* have signed a river treaty at time *t*. This dummy is built from the International Freshwater Treaty Database. We use a LPM estimator over the period 1961-2007. All the regressions include the following effects: year fixed effects, income-group time-varying effects continental time-varying effects and bilateral fixed effects. The overall effect of temperature and precipitations shocks are computed using "Delta method".

Appendix D: Downstream/upstream countries

Another interesting discussion concerns the role of countries' geographic location relative to the basin's common resource. Where does the change in temperature/precipitation have the most impact on the likelihood of signing a treaty, in the downstream country or in the upstream country? One could argue that since upstream countries have the ability to control river flows (e.g. through dams), the incentive to sign an agreement in the event of a water shortage could be zero for these countries.

Such a proposal, however, is based on the assumption that water storage by upstream countries is sufficiently large to compensate for the water shortage due to a warmer climate (and on the inability of the downstream country to respond in other ways). If this capacity is not met, it is likely that the signing of the treaty will depend on the temperature/rainfall in that upstream country. If we now consider downstream countries, especially weak countries (with economic and/or military power disadvantage), then the change in temperature/precipitation may not impact treaties, since these countries may not have the bargaining power to negotiate them. On the contrary, if the power asymmetry is reversed (strong country downstream vs. weak country upstream), then it may be the temperature fluctuation at that location that will be decisive. In short, from this narrative approach, it is difficult to know what to expect. We therefore propose a simple empirical test of whether location along the river matters. We estimate our baseline equation by adding for each pair only the temperature and precipitation of the downstream (column 1) and upstream (column 2) countries. The upstream/downstream dummy variable is also constructed from the shared watershed database (PRIO project). We only consider country pairs where the upstream/downstream relationship is clear, i.e. we do not consider river border cases or mixed upstream/downstream cases.

The results are ambiguous. On the one hand, precipitation has a greater effect in downstream countries, but on the other hand, temperature has a significant effect only in upstream countries. These results can therefore be interpreted in different ways, by focusing on temperature one could argue that upstream countries are the key players, while the results concerning precipitation are less conclusive. These ambiguous results explain our choice not to go into detail about upstream versus downstream countries in our baseline estimate. After all “it takes two to tango” and it is not sure that a systematic relationship can be established for dowstream/upstream countries. More data on the timing of climate shocks and their policy implications in each country, as well as the exogenous determinants of downstream and upstream country dependence and power asymmetry, can help advance this issue.

Table 9: Upstream versus Downstream countries

	(1)	(2)
Downstream country Avg Temp	0.0111	
	(0.0073)	
Downstream country Avg Prec	-0.0061^a	
	(0.0021)	
Upstream country Avg Temp		0.0138^a
		(0.0060)
Upstream country Avg Prec		-0.0041^b
		(0.0021)
Renew freshwater in i ($Clim_{it}$)	-0.0027	-0.0030
	(0.0204)	(0.0204)
Renew freshwater j ($Clim_{jt}$)	0.0145	0.0136
	(0.0199)	(0.0199)
Common international organizations	0.0002	0.0002
	(0.0003)	(0.0003)
Constant	-0.1812	-0.2662
	(0.2502)	(0.2502)
Observations	8,740	8,740
% fitted values ϵ [0; 1]	68.12	59.57
R-squared	0.502	0.502

Notes: Standard errors adjusted for clustering at the country pair level. a: p<0.01, b: p<0.05. The dependent variable is a dummy taking one when countries *i* and *j* have signed a river treaty at time *t*. This dummy is built from the International Freshwater Treaty Database. Climate variables comes from WorldClim. We use a Fixed Effect model over the period 1961-2007. All the regressions include the following effects: year fixed effects, income-group time-varying effects, continental time-varying effects and bilateral fixed effects.