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Design and change in transboundary freshwater agreements

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Abstract
This paper presents a systematic assessment of transboundary water treaties and their institutional evolution over time. While the majority of treaties tend to remain unchanged, others are renegotiated over time, either gradually by treaty amendment or abruptly by treaty replacement. This study examines the sources of treaty amendment, treaty replacement, and renegotiation. Treaty design features, such as conflict resolution mechanisms and duration mechanisms, make up the set of independent variables. Effects are also measured for a set of control variables including the geographical configuration of a basin, the number of signatories, a history of interstate militarized disputes, water variability, the basin's climate zone, and past renegotiations. Conflict resolution appears as a significant design feature for determining treaty stability, aided by asymmetrical basin configurations and bilateralism. The absence of conflict resolution is the main trigger for gradual change. The presence of a duration clause and a history of interstate militarized disputes are found to trigger abrupt change. Renegotiations become more likely after the first round of renegotiation, suggesting a temporal effect of path dependence on treaty evolution. This study adds to the work of scholars mapping transboundary basins at risk and provides further arguments to negotiate better and more specific treaties from the start, which include conflict resolution features that enable dialogue and rule modification while avoiding the need for formal treaty renegotiation.

Keywords International agreements · Transboundary water treaties · Institutional evolution · Gradualism · Flexibility mechanisms · Conflict resolution · Institutional resilience

1 Introduction

Most of the world's freshwater systems are transboundary in nature and cross various jurisdictions and ecosystems (Wolf et al. 2003). They include major and minor watercourses, rivers and streams, their tributaries, and connected lakes, and groundwater. Both

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transboundary basins and aquifers are often governed by water agreements. Between 1820 and 2007, approximately 688 international freshwater-related agreements have been signed with respect to non-navigational uses[1] of water (Giordano et al. 2014).

Bilateral and multilateral agreements are important legal instruments through which states make reciprocal commitments in the international arena, and transboundary water is no exception (Abbott and Snidal 2000). Environmental uncertainty about the distribution, timing and intensity of precipitation, increased water variability, and the broader consequences of climate change are some of the challenges that complicate the negotiations of transboundary water agreements (Giordano and Wolf 2003; Timmerman and Bernardini 2009; Dinar et al. 2015). Hence, institutional flexibility and its capacity to facilitate adaptation is especially relevant to international treaties dealing with transboundary waters (McCaffrey 2003; Jafroudi 2018).

Some parties to transboundary water agreements took advantage of available flexibility provisions and updated their legal commitments, but many others refrained from doing so. In some instances, the agreements were amended, reflecting a gradual evolution. In others, they were replaced by an entirely new treaty, a reflection of a more abrupt change (Campbell 2004). What are the sources of this variation? This paper takes on this important question by linking changing environmental conditions, institutional design, and the renegotiation of transboundary water treaties.

By exploring this nexus, theoretically as well as empirically, we aim to make two main contributions. First, our study sheds new light on the manners by which states respond and adapt to changing conditions on the ground. Considering the increasingly volatile and unpredictable climate around the world, its pernicious effects on water resources and supply, and the large amount of research suggesting that without the right institutions in place scarcity of resources, like water, could contribute to social instability or violent conflict,[2] understanding this matter is of great urgency. Some research already demonstrated this urgency in transboundary river basins. Nax (2016), for example, argues that, due to changing environmental conditions, the inclusion of flexibility mechanisms, drought provisions, amendment clauses and joint management institutions will be essential for the survival of the Indus Water Treaty between India and Pakistan.

Second, and from a more general perspective, this study goes beyond institutional design and provides a systematic account of the fate of international treaties after they were signed and entered into force. Following Koremenos et al.'s (2001) seminal article, research on the design of international agreements has grown exponentially. This trend did not skip the literature on environmental agreements (Mitchel et al. 2020) and transboundary water treaties (Conca et al. 2006; Dinar et al. 2011; Giordano et al. 2014; Mitchell and Zawahri 2015). Nevertheless, none of these studies and accompanying data sets pay attention to the "life cycle" of such agreements.[3] We use this rich literature as a springboard to develop several

[1] The non-navigational uses of water applies to uses of international watercourses and of their waters for purposes other than navigation and to measures of protection, preservation, and management related to the uses of those watercourses and their waters (Convention on the Law of Non-Navigational Uses of International Watercourses, 1997).

[2] An overview of this research is presented in Konca Ken and Dabelko D. Geoffrey, 2002, Environmental Peacemaking.

[3] For recent exceptions, see Haftel and Thompson (2018) and Thompson et al. (2019) with respect to international investment treaties and Eilstrup-Sangiovani (forthcoming) and Jupille et al. (2013) with respect to international organizations.

conjectures regarding the implications of treaty design to the *practice* of adaptation and renegotiation.

The purpose of this study is to better understand why and how specific treaties dealing with transboundary waters evolve over time while others remain unchanged and to draw lessons for future treaty negotiations in this context. Building on extant research, this study hypothesizes that the type of institutional evolution (gradual change, abrupt change, or no change) is affected by the institutional design of the treaty and the presence of flexibility mechanisms that allow for a treaty to be adjusted in the future. It also theorizes that context- and temporally linked events (such as path dependence) are likely to affect the evolution of transboundary water treaties.

The paper proceeds as follows. The next section provides a theoretical framework for explaining treaty evolution over time, using existing research on institutional change as a springboard. The third section presents the research design and results, followed by a discussion. The final section concludes and draws linkages between freshwater treaty evolution and negotiation.

2 The evolution of transboundary water treaties: a rudimentary typology

Based on a review of the literature, this section aims to clarify the distinction between two generic types of institutional change—gradual and abrupt change—as well as the absence of change (or institutional inertia) and how these plays out in the evolution of transboundary water treaties.

Gradual change is considered to be a slow-moving process (Streeck and Thelen 2005), and rather than abruptly dismantling the rules, actors slowly subvert, build around, or redirect them. The model developed by Mahoney and Thelen (2010) identifies four modes of incremental change, of which "layering" (i.e., the practice of creating new rules alongside old ones) and "conversion" (i.e., the interpretation of old rules in new ways) correspond closely with our interpretation of gradual change in water treaties. In North's view (1990), it is the evolution of informal rules or soft law, as opposed to hard law such as treaties and laws, which is the main driver of gradual change. In international treaties, this process of gradual change is reflected in sequential regime development (Jupille et al. 2013) and often characterized by consecutive amendments of a formal treaty. The study of Abbott and Snidal (2002) identifies gradual change when signatories adopt new rules in the form of amendments or protocols meant to institutionally update a treaty according to new circumstances. For example, in an effort to effectively implement the 1990 Convention for the International Protection (ICPE) of the Elbe, the agreement was updated in 1991 with a protocol that granted the earlier established river commission enhanced legal capacity.

Abrupt change is perceived as more intentional than gradual change; it is a process where formal rules are deliberately changed through a political process (Nexon 2012). While gradual change tends to be limited in scope, abrupt change is usually more far-reaching. Abrupt change can be sporadic or frequent but is usually referred to as a period of instability and institutional breakdown, followed by a more radical transformation (Levitsky and Murillo 2013). The new equilibrium then remains in place or gradually evolves for another prolonged period. Following this view, we identify abrupt change when a new treaty replaces a former one in its entirety or when members to the treaty choose to leave it. An example of this is the 1994 agreement on the Meuse, which was replaced in 2002 by the International Treaty for the Meuse.

Political institutions can also change discontinuously over time, and patterns of change may alternate during regime development. Institutions may thus evolve gradually over prolonged periods of time and then remain stagnant for a while before changing abruptly (Roland 2004). The process of treaties evolving both through amendment and replacement is referred to as "renegotiation" (Haftel and Thompson 2018). The 1972 Great Lakes Water Quality Agreement between the USA and Canada illustrates such a process; the treaty was amended and revised several times in 1973, 1978, 1983, and 1987. While the first revisions in 1973 implied minor amendments to the initial agreement (i.e., gradual change), the 1978 agreement supersedes and replaces the initial treaty (i.e., abrupt change), and in 1987, multiple pollution-related articles were once again amended (i.e., gradual change).

Finally, *institutional inertia* (*no change*) includes the many transboundary water treaties that are persistent over time. For example, the 1952 agreement signed between the USSR and Romania over the Prut River and the 1954 agreement between Yugoslavia and Austria over the Drava River were never revised despite the fact that some signatories politically disintegrated and ceased to exist. While some of these treaties are abandoned, others remain unchanged or outdated for a long time despite what Carlson and Doyle (2002) refer to as "fluctuations in the behavior of its components or the environment." For example, in the Rhine basin, devastating pollution became imminent as early as 1932. Nevertheless, it took 18 years for the riparian states to agree on the establishment of the International Commission for the Protection of the Rhine and it took another 26 years for them to conclude an international convention specifically aimed at reducing chemical pollution in the Rhine basin (Huisman et al. 2000). Uncertainty, path dependency, risk-aversion, and free-riding problems may all impede the collective action required to alter existing rules and as such become sources of institutional inertia. This study identifies institutional inertia when a treaty has not changed, either gradually or abruptly, since its signatory date.

3 The role of institutional design and path dependence in institutional evolution

According to rational design theory, states and other actors choose and design institutional arrangements to further their own interests (Koremenos et al. 2001), hedge against uncertainty and minimize risks (Haas 1990). This is an interest-based, actor-centered approach by which individuals select institutions based on a set of their preferences (Fioretos et al. 2016) and by which institutions generate stability by limiting the range of change. Historical institutionalism, on the other hand, holds that institutions are not typically created for functional reasons and calls for historical research to trace the processes behind the creation, change, and persistence of institutions, thereby pointing to the relevance of context, time, and path dependence (Amenta and Ramsey 2010).

The early historical institutionalist literature employed a "punctuated equilibrium" model of change, in which long periods of stability are interrupted by periods of abrupt and far-reaching change (Krasner 1988). These studies distinguished between what Swidler (1986) calls "settled" times, in which the rules of the game are firmly established, and "unsettled times," when the rules are up for grabs and radical change becomes possible. However, as scholars such as Mahoney and Thelen (2010) have already shown, punctuated equilibrium models fail to account for slow and gradual change and today considerable literature within the historical institutionalist perspective argues for the variable nature of change processes (Nexon 2012).

Institutional design is an important determinant of the dynamics of global environmental regimes (Young 2010) and a regime can be designed to be rigid or flexible. A flexible design enables change, either following rational considerations of the actors involved (McCaffrey 2003) or following earlier created institutional paths that enhance the likelihood of future change—also referred to as path dependence (Capoccia 2015). In contrast, when flexibility features are missing, change may be harder to negotiate and implement and a regime may be considered rigid.

The ability of water treaties to adapt to change depends on the flexibility of their institutional design. Mechanisms for conflict resolution are especially relevant, as they are specifically designed to address future changes in resource availability and the disputes that may emanate from them (Fischhendler 2004; Wolf 2007). In general, flexibility mechanisms can be divided into two groups, each of which is designed to affect institutional change differently: transformative and adaptive flexibility (Koremenos 2001). Transformative flexibility refers to clauses allowing for a methodical transformation of the institution such as provisions for amendment or conflict resolution. Adaptive flexibility allows parties to respond to unanticipated events by resorting to the use of escape clauses while preserving the agreement in its original form. Finally, change may also be enabled by path dependence, which is a frequently used concept in discussions about policy change and water governance (Mukhtarov 2011). Below, we set out our arguments on how transformative and adaptive flexibility, as well as path dependence may affect the different types of institutional change. The dependent variables and associated hypotheses are further presented in Table 1.

3.1 Transformative flexibility and gradual change

The role of transformative flexibility in institutional design is conceptualized with the presence of amendment, periodic review, and conflict resolution mechanisms.

Mechanisms for amendment and periodic review correspond with the concept of "layering" and the practice of creating new rules alongside old ones. Amendment and periodic review

Table 1 Dependent and independent variables

Dependent variables	Measure	Independent variables	Hypotheses
a. Gradual change	Amendment	Transformative flexibility mechanisms: Amendment, periodic review, dispute resolution	Hypothesis 1 (a) The inclusion of transformative flexibility mechanisms such as amendment and periodic review in transboundary freshwater treaties increases the likelihood of gradual change. (b) The presence of dispute resolution mechanisms in such treaties decreases the likelihood of gradual change and treaty amendment.
b. Abrupt change	Replacement	1. Adaptive flexibility mechanisms for: Withdrawal, unilateral denunciation, duration, termination	Hypothesis 2 The inclusion of adaptive flexibility mechanisms, such as escape clauses and duration and termination mechanisms, increases the likelihood of abrupt change and treaty replacement.
c. Gradual and abrupt change	Renegotiation	Previous renegotiation (amendment or replacement)	Hypothesis 3 If a treaty was renegotiated in the past, the likelihood increases that it will be renegotiated in the future.

provide parties with an opportunity to tackle unforeseen circumstances or evaluate treaties at specific times in order to update them according to new knowledge and changing circumstances (Susskind 1994). When looking at transboundary water treaties, a few historic examples demonstrate the relevance of transformative flexibility in enabling gradual change. The amendment mechanism in the Great Lakes agreement between the USA and Canada facilitated a gradual adaptation of the treaty, manifested by three consecutive amendments after the treaty was signed in 1978, and the amendment ("minute") mechanisms in the 1944 agreement between the USA and Mexico over the Rio Grande have allowed for gradual change at times when the parties considered it in their interest to update the agreement (Capoccia, 2014). Consequently, we expect that treaties containing amendment and periodic review mechanisms are more likely to change gradually over time.

Dispute (*or conflict*) *resolution*[4] is considered particularly important in transboundary water treaties as it has the ability to address future uncertainties and mitigate disputes caused by a change or decline in resource availability (Capoccia, 2014). In fact, previous research of transboundary water governance suggests a direct link between institutions, change, and conflicts over water (Petersen-Perlman et al. 2012). The study of Petersen-Perlman et al. found that when the rate of hydrological change, caused by an unprecedented degree of uncertainty and instability of the earth system, exceeds the institutional capacity to absorb that change, conflicts over water become much more likely. As such, conflict resolution becomes even more relevant as it provides the institutional capacity for dialogue and enables decision-makers to mitigate tensions arising from commitment problems or informational challenges while preserving the existing treaty (Giordano et al. 2005; Subramanian et al. 2012; Koremenos and Betz, 2013). Conflict resolution is different from other transformative flexibility mechanisms such as amendment and periodic review in that it foresees the possibility of dialogue and reinterpretation of an existing treaty while maintaining it (Hayton and Utton 1989), making formal amendments less likely. While there are different types of conflict resolution, ranging from more informal approaches such as negotiation and mediation to more formal procedures including arbitration and adjudication (De Bruyne and Fischhendler, 2014), all provide disputants an alternative channel of communication. It should be noted that the use of these mechanisms does not imply that the outcomes of dispute settlement will result in formal treaty amendments. That is unless the treaty specifically foresees in the recording of these outcomes, usually through a mechanism of periodic review, such as the minute mechanism in the 1944 treaty between the USA and Mexico over the Rio Grande. Many early water treaties that contain conflict resolution clauses have indeed not been formally amended, such as the 1978 agreement between the Federal Republic of Germany and the European Economic Community and the Republic of Austria on cooperation on management of water resources in the Danube Basin, and the 1954 Convention between the government of the Federal People's Republic of Yugoslavia and the Federal Government of the Austrian Republic concerning water economy questions relating to the Drava.[5]

[4] Conflict resolution, dispute resolution, and dispute settlement are used interchangeably throughout the text. The corresponding variable is labeled DSM for the statistical analysis.

[5] In this case, the absence of formal amendments does not capture all changes that took place since the signature of the treaty: the bilateral treaty between Germany and Austria on the Danube converged with the 1994 basin-wide Convention on Cooperation for the Protection and Sustainable Use of the Danube River. Also, in the particular case of river basins in the European Union, since the year 2000, the EU Water Framework Directive has been declared highest priority in all European basins, affecting policy changes in water governance that not resulted in the revision of the existing treaties on the continent.

3.2 Adaptive flexibility and abrupt change

The role of adaptive flexibility is conceptualized with the form of withdrawal, duration, denunciation, and exit clauses, which enable abrupt change such as treaty replacement.

Adaptive flexibility mechanisms such as *escape clauses*, *including withdrawal and unilateral denunciation*, can facilitate the process of states suspending or denouncing their participation in an agreement.[6] The original rules will then remain intact, but the agreement will lose bearing and impact as members leave. A shift like this corresponds with Mahoney and Thelen's concept of "drift," where the impact of existing rules is altered by changes in the external environment. Other adaptive flexibility mechanisms, such as *duration or termination clause*s, permit states to change an institution in a more profound way and may require renegotiation of new rules and regulations for the treaty to survive. This corresponds with the concept of "displacement," which includes the removal of existing rules and the introduction of new ones (Mahoney and Thelen 2010). For example, Article XII of the Indus Waters Treaty, signed in 1960 between the government of India, the government of Pakistan, and the International Bank for Reconstruction and Development, conditions that the treaty can only be terminated if replaced by another one. In this case, this more stringent approach should be seen in the context of the Indus Water Treaty, being one of the few examples in the world of a successful settlement of a major international river basin conflict, with negotiations that lasted for 8 years.

3.3 Path dependence and renegotiation

Following the logic of path dependence, preceding steps in a particular direction may trigger further movement in the same direction (Pierson 2000), making it more likely for a treaty to be renegotiated in the future if it has been renegotiated before. Possibly, the transaction costs of the first renegotiation are high but decline thereafter (as negotiators become more experienced and gain knowledge and expertise). Conversely, once an institution has been established and started down a track, the cost of reversal may be high (Levi 1997). The Niger River Commission, for example, was negotiated in 1964, then amended in 1969 and 1973, before it was replaced by the Niger Basin Authority in 1980, which was at its turn revised and amended by adding financial procedures in 1987.

4 Research design

This study strives to estimate the effects of treaty design and other explanatory variables on the duration of transboundary water treaties before they are amended or replaced. Our unit of analysis is the treaty. The data set is a comprehensive sample of 144 transboundary water treaties signed between 1950 and 2004 and included in the Transboundary Freshwater Dispute Database (TFDD) (n.d). In line with earlier research, we included only treaties that govern transboundary waters (aquifers, rivers, or lakes) and define freshwater as "a scarce or consumable resource, a quantity to be

[6] Withdrawal and unilateral denunciation refer to a unilateral act by which a state that is currently a party to a treaty ends its membership in it. In the case of multilateral agreements, this generally does not affect the treaty's continuation in force for the remaining parties. For bilateral agreements, in contrast, denunciation or withdrawal by either party results in the termination of the treaty.

managed or an ecosystem to be improved or maintained" (Hamner and Wolf, 1998). We therefore exclude global conventions as well as treaties dealing with navigation, fishery, borders, and territorial issues. In addition, given our interest in treaty design, we include only treaties for which the entire text is available and that are written or translated into English, French, German, or Dutch.[7]

We employ the statistical method of event-history analysis. This type of technique estimates the "risk" that an event will take place as time elapses and is thus appropriate to account for variation in the timing of events (Box-Steffenmeier and Jones 2004). In the analysis here, the event is the renegotiation of an agreement, such that the dependent variable scores zero for each year after the agreement's entry into force in which it remained intact. This variable scores one if a renegotiation (the "event") took place and then exits the analysis. Thus, this method estimates the probability that an agreement will be renegotiated next year, given its previous history and values on relevant independent variables. The results below are reported as "hazard ratios." That is, independent variables with estimates that are lower than one point to a lower risk of renegotiation and values higher than one indicate that renegotiation is more likely. We employ a specific event-history model that allows for time-varying independent variables, known as a Cox proportional hazard model. Standard errors are clustered by treaty to take into account the possibility that within-treaty observations are not independent of each other. In addition, the climate zone in which the water resource is found may affect treaty change. We therefore include a climate zone fixed-effects, based on the Köppen–Geiger (Köppen 1936; Geiger 1961) and the Trewartha climate classifications (Trewartha 1968; Peel et al. 2007) in all statistical models.[8]

4.1 Dependent variables

The analysis examines the sources of three dependent variables: *Amend*, *Replace*, and *Renegotiate*. As discussed in the theoretical section, the former two serve as proxies for gradual and abrupt change, respectively, and the latter is their sum.

Amend refers to instances in which a treaty was gradually amended or revised, but otherwise remained intact. It scores one in the year in which a treaty was amended and zero otherwise. *Replace* refers to cases in which the old treaty was abruptly terminated and a new one was signed. It scores one in the year in which a treaty was replaced and zero otherwise. Finally, *Renegotiate* scores one in a given year if a treaty was either amended or replaced. A first glance at the data shows that there is substantial variation in the dependent variables. As Fig. 1 demonstrates, about two thirds of the sample remained unchanged throughout the period, about one quarter was amended, and the remaining 8% were either replaced or both amended and replaced. Considering that only a handful of agreements were replaced, one should interpret the statistical results with respect to this dependent variable with caution.

4.2 Independent variables

The main explanatory variables of interest are specific design features that provide transboundary water agreements with either transformative or adaptive flexibility. The following design elements reflect adaptive flexibility: the presence of withdrawal, denunciation, and

[7] We were not able to code a handful of treaties in Hungarian, Ukrainian, and Russian.

[8] These are temperate, continental, tropical, dry, and semi-dry climate zones as well as mixed for basins that transcend climate zones. The polar zone is excluded from the analysis, as it covers no transboundary waters.

termination provisions as well as a clause that specifies a fixed duration. The additional variables presented in Table 3 (Appendix), labeled *D_Withdrawal*, *D_Denunciation*, *D_Termination*, and *D_Duration*, are all binary and score one if a provision exists in the agreement and zero otherwise. We account for transformative flexibility with three additional design features: the inclusion of provisions that allow parties to amend the agreement as well as articles that specify mechanisms for periodic review and dispute resolution. These variables (Table 3, Appendix), labeled *D_Amendment*, *D_Periodic Review*, and *Dispute Settlement Mechanism* (Table 2), are, too, binary and score one if the relevant clause appears in the agreement.

The coding of all these design features is based on an existing data set developed by De Bruyne and Fischhendler (2013) and was further expanded and updated for this study. Figure 2 reports the frequency of the various design features in the sample. It indicates that provisions related to transformative flexibility are more common than those related to adaptive flexibility. For example, transboundary water agreements are much more likely to allow for future amendment, compared to withdrawal or termination. Of particular note is the high number of agreements that include a mechanism for dispute resolution (labeled "DSM").

One example of an agreement that includes a DSM is the 1994 Israel–Jordan peace treaty, which contains provisions for shared management of the Jordan River, provides for third-party mediation in case of dispute. Another is the 1978 Convention related to the creation of the Gambia River Basin Development Organization, signed by Gambia, Guinea, and Senegal, which refers the disputing parties to the International Court of Justice. Considering its great theoretical importance not only in transboundary water agreements but also in international politics more broadly, and its recurrent appearance in the data, our empirical analysis pays particular attention to this institutional feature.

As discussed in previous sections, the likelihood of treaty renegotiation may not depend only on institutional design but also on previous instances of treaty change. Consistent with the logic of historical institutionalism, past behavior may affect current preferences and actions. We capture this possible dynamic with *Past Change*, which is the number of previous

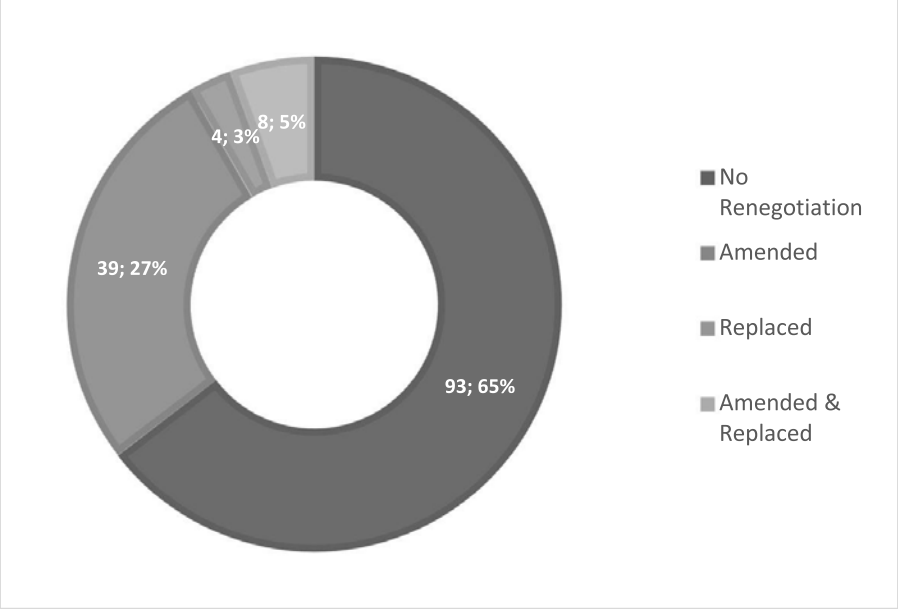

Fig. 1 Distribution of type of institutional evolution in sampled transboundary water treaties

Table 2 Event-history analysis of the sources of water treaty change, 1950–2004

	(1) *Amend*	(2) *Replace*	(3) *Renegotiate*
Dispute Settlement Mechanism	0.624** (−2.44)	1.308 (0.48)	0.714** (−1.97)
Militarized Interstate Dispute	1.163 (0.48)	2.883** (2.30)	1.363 (1.06)
Bilateral Agreement	0.718* (−1.71)	1.285 (0.50)	0.773 (−1.53)
Up/Down Stream	0.747 (−1.57)	0.823 (−0.33)	0.770* (−1.66)
Past Change	4.052*** (9.95)	2.485*** (5.70)	3.554*** (11.02)
Agreement Age	1.009 (1.17)	1.045* (1.92)	1.014** (2.07)
Wald χ^2	122.57***	45.33***	163.33***
N (*Treaties*)	144	144	144
NT (*Treaties* × *Year*)	4174	4174	4174

Figures in parentheses are *t* statistics. All models are Cox proportional hazard. Values greater than 1 indicate higher risk and those less than one indicate lower risk. Standard errors are clustered by treaty. All models include climate zone fixed-effects

*$p < 0.1$, **$p < 0.05$, ***$p < 0.01$

renegotiations of a given transboundary water agreement. This variable ranges from zero to six. In fact, in our sample, about half of the observations that indicate at least one previous change, were renegotiated at least twice. Three agreements score the maximum value of six on this variable: the International Boundary and Water Commission USA-Mexico, the Lake Geneva Pollution Agreement, and the Recommendations for the Solution to the Border Sanitation Problems (in the Rio Grande).

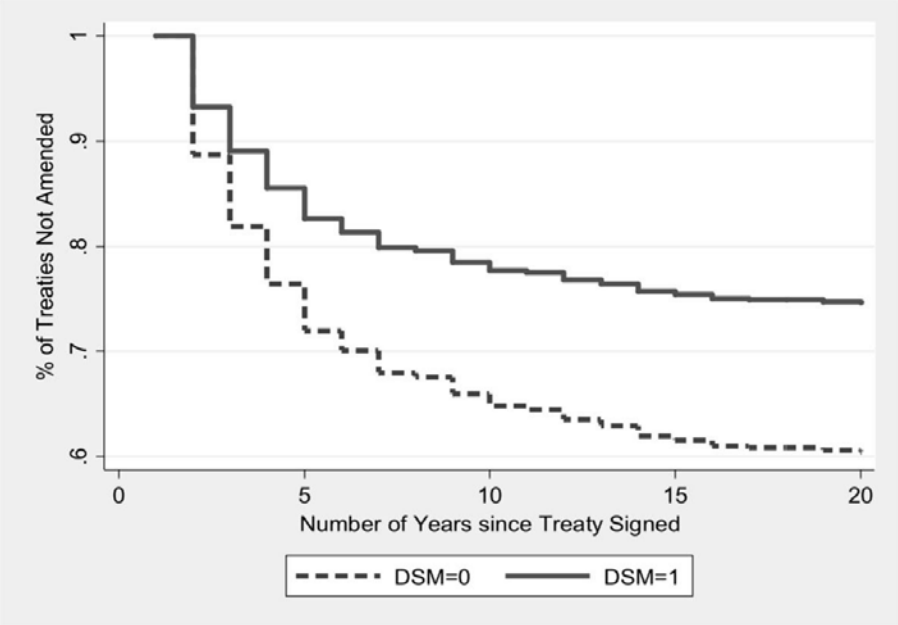

Fig. 2 Survival estimates at different values of DSM. The predicted number of amended treaties for a given number of years since the treaty was signed, based on different values on *Dispute Settlement Mechanism*, is shown

4.3 Control variables

To reduce the risk that the statistical results do not suffer from an omitted variable bias and that the effect of institutional design on treaty change is not spurious, we include several control variables that might affect the dependent variables.[9] First, the geographical configuration of a water resource may matter. Here, a common distinction is between upstream users (that can easily affect downstream ones) and the symmetry of border-rivers and shared lakes, where water users are mutually interdependent. Extant research suggests that power asymmetry inhibits international cooperation (Ovodenko 2014). Potentially, symmetrical relationships are more likely to induce treaty change as any change in the physical environment of a lake or border-river affects all riparian states simultaneously, creating incentives to adopt common adaptation strategies, revise earlier agreements, and avoid the costs of non-cooperation for all. We control for this possibility with *Up/Down Stream*, which scores one if the treaty involves an up/down stream water resource and zero otherwise. We used the TFDD as well as our own judgment to code this variable.

Second, armed disputes between signatory states might affect their willingness to cooperate in other issue-areas, such as water, on the one hand, and lead to a period of instability and institutional breakdown, followed by a more radical transformation, on the other. We account for this factor with *Militarized Interstate Dispute* (MID),[10] which scores one if a MID between the parties to the agreement was initiated in a given year and zero otherwise. We employ the MID 3.0 data set to produce this variable (Ghosn et al. 2004).

Third, cooperation theory suggests that as the number of parties to an agreement affects the prospects of reaching an agreement (Koremenos 2005). It stands to reason that this factor also affects the likelihood of renegotiation and institutional change (Eilstrup-Sangiovanni forthcoming). We are unaware of research that examines the implications of the number of members on treaty renegotiation and could imagine at least two alternative possibilities. On the one hand, renegotiation may be easier to obtain when the number of parties is small. On the other hand, a small number of parties may be able to negotiate an agreement that better reflects the preferences of the parties and the environmental conditions in the first place, obviating the need for either gradual or abrupt change. Be that as it may, we account for this possibility with *Bilateral Agreement*, which scores 1 for bilateral treaties and zero for treaties that include three states or more. Of the 144 treaties in our sample, close to 80% are bilateral.[11]

[9] In addition to variables mentioned herein, we controlled for two additional variables. First, the *1966 Helsinki Rules on the Uses of the Waters of International Rivers* were found to heavily influence state practice and preferences in the field of transboundary water management (Bourne 1996). We therefore added a dummy variable that scores one for all years after 1965. Second, *water variability* may cause riparian states to deviate from the treaty (Bhaduri 2006) or adjust it according to new levels of water availability. One might therefore expect to greater change in basins where resource variability is high. We included a variable that scores one if water variability is above 0.50 and zero otherwise. Both variables were statistically insignificant and did not change the results. They are on file with the authors.

[10] Militarized interstate dispute (MID) are "cases of conflict in which the threat, display or use of military force short of war by one member-state is explicitly directed towards the government, official representatives, official forces, property, or territory of another state. Disputes are composed of incidents that range in intensity from threats to use force to actual combat short of war" (Jones et al., 1996: 163).

[11] To further probe the implications of this variation, we ran the analysis for bilateral and multilateral treaties separately (excluding *Bilateral Agreement*). The small number of agreements that score one on *Replace* (9 for bilateral and 4 for multilateral treaties) did not permit a meaningful statistical analysis. We therefore report results only for *Amend* and *Renegotiate*. The results reported in the Appendix (Table 4) remain intact.

Fourth, the impact of a series of climatic variables and environmental stressors was examined including climatic zone, flood frequency, and increased *Water Variability*. Because the first two variables resulted insignificant due to lack of data,[12] only water variability was included in the final analysis. Water variability in a basin can be a sufficient motivation for parties to renegotiate. To determine variability in basins, we use the co-variance value (with threshold 0.50) that reflects inter-annual precipitation over all monthly observations for the time period 1901–2001.[13]

Finally, older agreements may become obsolete as the parties' interests and environmental conditions change (Haftel and Thompson 2018). We might expect, then, that the likelihood of renegotiation, whether gradual or abrupt, will increase with the agreement's age. We control for this possibility with *Agreement Age*, which is a count of the number of years passed since the treaty was signed. The mean age in our sample is about 40 years.

5 Results and discussion

The statistical analysis indicates that most design features we considered have no discernable impact on treaty change. An important exception to this general finding is the presence of a conflict resolution or dispute settlement mechanism.[14] This section therefore zeroes in on this key institutional feature and reports the result on other institutional features in the Appendix (Table 3). Table 2 presents three Cox proportional hazard models of the determinants of treaty amendment, replacement, and renegotiation, respectively. Figure 3 reports the substantive effect of *Dispute Settlement Mechanism* and Fig. 4 repeats this exercise for *Past Change*.

As Table 2 indicates, the results offer strong support to the hypothesis 1b that dispute settlement provisions tend to delay changes in transboundary water agreements. Consistent with our theoretical framework, *Dispute Settlement Mechanism* is smaller than one and highly statistically significant in models 1 (amendment) and 3 (renegotiation), indicating that, indeed, those water treaties that offer a mechanism for conflict management within the treaty are less likely to require (gradual) adjustments. Splitting the sample to bilateral and multilateral agreement does not change this conclusion. The effect of the DSM variable is substantively sizable as well. As Fig. 3 shows, the model predicts that 40% of the treaties without a DSM will be amended after 20 years, but only 25% will be amended in the same time period if a DSM is included.[15] On the other hand, this variable is statistically insignificant in model 2, suggesting that the inclusion of dispute settlement provisions does not postpone the more abrupt treaty replacement. Possibly, such rules are more useful in addressing minor disagreements, but are less instrumental in dealing with major ones. That being said, as was already

[12] Due to the number of climate zones (4), there was insufficient data (treaties) per category, while data regarding floods was available only for treaties signed after 1980.

[13] Precipitation data is used instead of run-off data because it is available over a much longer time frame (World Bank 2009).

[14] Another minor exception is the strong positive effect of fixed duration on treaty replacement. This is not surprising, as agreements that are in force for a limited number of years require renewal or are otherwise automatically lapsed.

[15] Both curves start at one in time zero, reflecting the fact that no treaty is expected to be amended when it is first signed. As time passes, more and more treaties are expected to be amended, but the number of amended treaties is higher for treaties that do not include a DSM. As one can see in Fig. 3, the curve for such treaties reaches 0.6 after 20 years, which means that 60% of the treaties are expected to remain intact, and by implication 40% are expected to be amended.

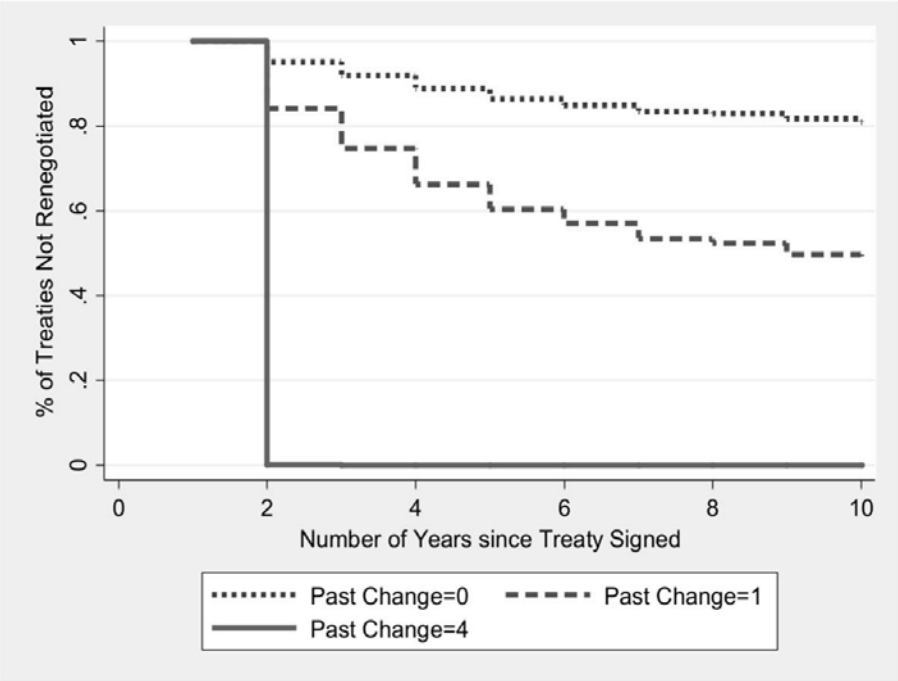

Fig. 3 Survival estimates at different values of past change. The predicted number of renegotiated treaties for a given number of years since the treaty was signed, based on different values on *Past Change*, is shown

mentioned, the small number of replaced agreements warrants caution in the interpretation of these last results.

The significance of dispute resolution as a variable supports an increasing amount of research that presents this as a key design feature for maintaining the stability of institutions and their ability to overcome the collective action problems (Giordano and Wolf 2003) and

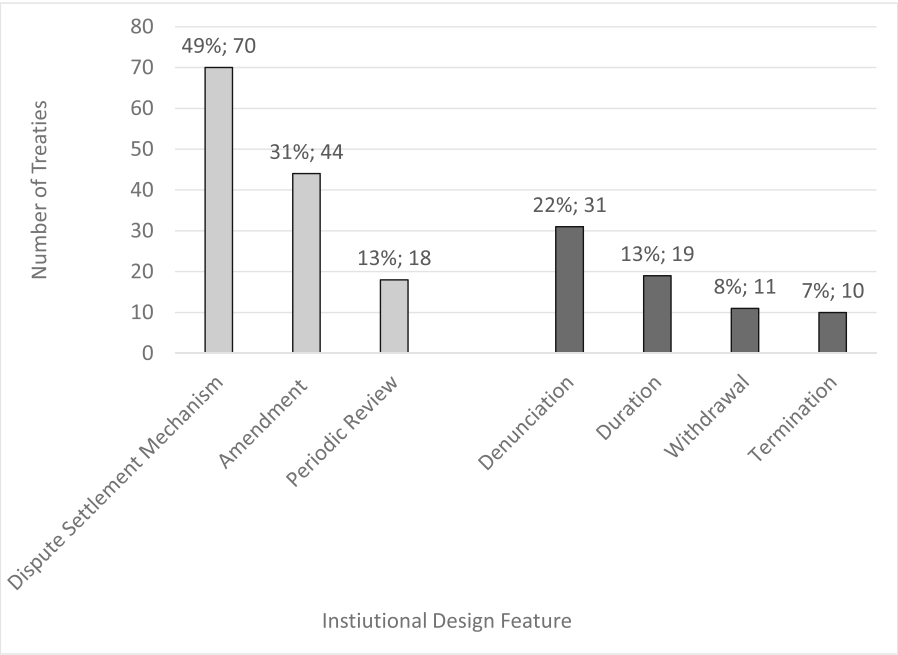

Fig. 4 Distribution of mechanisms for gradual and abrupt change in sampled transboundary water treaties. Mechanisms for gradual change are dispute settlement mechanisms, amendment, and periodic review. Mechanisms for abrupt change are denunciation, duration, withdrawal, and termination

strengthen the institutional resilience of transboundary water treaties in particular (De Stefano et al. 2017). Their inclusion may further encourage state parties to maintain cooperation over time without the need to formally alter the agreements between them (Conca et al. 2006). In some of the treaties in our sample, dispute resolution is included after an amendment, suggesting that it is considered to provide the necessary institutional capacity for mitigating issues arising from commitment problems or informational challenges.

The design variables that were expected to facilitate treaty replacement (withdrawal, denunciation, duration, and termination) appeared to have no impact (hypothesis 2), except for *Duration*, which came out as highly significant (Appendix, Table 3). As such clauses for duration appear to be more effective than denunciation, which occurs more frequently in treaties but has no impact on treaty change.

We find robust empirical evidence to the hypothesis 3 regarding the impact of previous renegotiations. As reported in Table 2, *Past Change* is larger than one and highly statistically significant in all three models. Thus, to the extent that a treaty was amended or replaced in the past, it is very likely to be renegotiated again sooner rather than later, no matter gradual or abrupt. The substantive effect of this variable is quite dramatic as well. Figure 4 shows that only 20% of the treaties that were not amended or replaced previously are predicted to be renegotiated within a 10-year period (model 3, Table 2). This number climbs to 50% if a treaty was renegotiated at least once in the past and reaches 100% (after only 2 years) if the treaty was renegotiated at least four times in the past. This finding comports with the idea that treaty change is path dependent. Earlier research in the field of transboundary water cooperation indeed found that the existence of at least one treaty may provide the context for continued negotiations, which could also take the form of additional agreements (Giordano et al. 2014).

Turning to the control variables, the hazard ratio of *Militarized Interstate Dispute* is larger than one in all models and statistically significant with respect to *Replace*. It is (weakly) statistically significant with respect to *Amend* and *Renegotiate* with respect to multilateral agreements (Appendix, Tables 4 and 5). It appears, then, that armed conflicts tend to hasten treaty change, but only under specific circumstances. While these relationships merit a more fine-grained analysis in future research, this finding is in line with research in the field of transboundary water governance arguing that while an abrupt breakdown of the rules entails the temporary loss of functionality, it may also offer a window of opportunity for a radical shift in water governance (Herrfahrdt-Pähle and Pahl-Wostl 2012).

Up/Down Stream is smaller than one in all models and weakly statistically significant with respect to *Renegotiate*. These results suggest that asymmetrical relationships are associated with a longer duration of the original treaties.[16] Presumably, lopsided power relations result in agreements that favor the parties with greater bargaining leverage, who then loath to change them. In river basins, power imbalance can enable upstream users to block or impose institutional changes, even when these are opposed to the preferences of downstream users, which eventually drives up the costs of adjustment for all parties involved (Ostrom 2005). The statistical weakness of these results warrants some caution in their interpretation, however.

The hazard ratio of *Bilateral Agreement* is smaller than one in relations to *Amend* and *Renegotiate* and weakly statistically significant with respect to the latter.[17] These results

[16] For example, the 1954 treaty on the Drava, signed between Yugoslavia and Austria, was never amended.
[17] For example, the multilateral 1977 Organization for the Management and Development of the Kagera River Basin, was amended as little as a year later, in 1978.

suggest that multilateral transboundary agreements tend to be renegotiated more quickly than bilateral ones. Possibly, then, multilateral agreements produce discontent for at least some parties and, in turn, propel a gradual change more rapidly. This result follows early scholarship stating that alliance formation and maintenance are much harder in a multilateral than in a bilateral international system (Waltz 1979). Hence, bilateral negotiations may make it easier for parties to reach consensus over non-formal amendments, which results in greater institutional stability.

Finally, as expected, the age of the agreement is positively associated with treaty change. The estimate on *Agreement Change* is larger than one and statistically significant with respect to *Replace* and *Renegotiate*. It is also statistically significant with respect to *Amend* when only bilateral agreements are included in the sample. This result suggests that treaty-pairs find it easier to adjust older agreements more gradually than multiple parties. Importantly for our purposes here, the hypothesized effects of dispute settlement mechanisms and previous renegotiations are robust to the inclusion of the various control variables in the statistical analysis.

Overall, this research shows that a majority of treaties does not change after their establishment. A few factors may explain this: first, the absence of change in treaties may not always reflect reality accurately as the signature of treaties often reflects a symbolic and formalized moment of cooperation between countries, which provides the ground for further, informal forms of cooperation and change. Because those changes are not formalized they are not reflected in the database.[18] In-depth case studies of change in international river basins could track these forms of informal cooperation. Second, the transaction costs of changing international institutions may be perceived to be too high by negotiators, which can contribute to regime rigidity or which locks regimes into a certain, known path (e.g., revisions by periodic review). The finding that path dependency in treaties is persistent also helps to explain why many water treaties remain unchanged despite, i.e., rational challenges to a previously agreed upon status quo.

6 Conclusion

At the theoretical level, institutional change is often studied from a functionalist perspective, which considers change to be the rational consequence of decision-makers responding to changing conditions. It has been argued that this theoretical framework is limited, with historical institutionalists urging to consider the broader historical framework in order to clarify why some institutions survive for a very long time despite the fact that they are no longer adapted to their environment. This study applies this theoretical framework to the field of transboundary water governance by empirically examining the correlation between institutional design and change in treaties. However, transboundary water problems are complex and involve multiple networks and actors. As a result, their management is often context specific and may require an adaptive approach that a statistical analysis is not designed to capture. The trajectory of each institution is also influenced by a myriad of factors and conditions, which make it impossible to model with precision how transboundary water treaties will evolve over

[18] See also reference note 6.

time. Descriptive research and in-depth case studies would be required to investigate the specifics of institutional change in the agreements that govern international river basins and especially the changes that took place over the past decade.

This is the first study of its kind to craft the dependent variable according to institutional change versus stability and to operationalize it in transboundary water institutions. Also, the hypothesized correlation that change in the stability of a treaty may be triggered by its institutional design is an approach rarely taken among scholars. Our most significant finding regarding this correlation is that the presence of dispute resolution makes (gradual) change in treaties less likely. Also, regardless the context in which an agreement is negotiated, institutional design matters and should be considered and unpacked as an explanatory factor of change in institutions.

On a practical level, it has already been argued that current scenarios of rapidly unfolding climate change may trigger the need for radical change and for climate-proofing the world's water treaties (Cooley and Gleick 2011; Vörösmarty et al. 2015; Pahl-Wostl et al. 2016; Gupta 2016). In reality, however, we see very little radical change taking place (in the form of renegotiating existing treaties) and if changes do occur, they tend to occur more gradually. Moreover, we see no impact of the selected climate-related variables on institutional change.[19]

This study suggests that treaties tend to stick around, despite changes in the environment, which gives policy makers a clear incentive to negotiate comprehensive and flexible agreements. Meanwhile, unfolding scenarios of climate change and increased water scarcity in the world potentially raise the transaction cost of transboundary water cooperation and the cost of crafting new agreements and institutions. This further implies that policy makers may have to make do with the institutions that already exist (Michonski and Levi 2010). Yet the correlations we found between institutional design and type of treaty change imply that negotiators can craft the future path and evolution of an international treaty by getting the design right. For example, if the end goal is to replace an existing treaty over time, adopting *withdrawal*, *denunciation*, *and termination* will not serve their purpose. Instead, they should spend their energy negotiating a *duration* clause. If the end goal is long-term stability, including a dispute resolution mechanism will allow them to work inside the boundaries of an existing institutional setting. As this article demonstrates, a wealth of institutional capacity in the field of transboundary water governance already exists. Further research should determine what other types of institutional mechanisms may best serve the purpose of climate proofing transboundary water treaties.

[19] We note that the sample of agreements on which our statistical analysis is based ranges from 1950 to 2004, which could further explain the limited impact of climate change.

Appendix

Table 3 Additional design variables

	Amend	*Replace*	*Renegotiate*
D_Periodic Review	0.858 (− 0.63)	1.303 (0.41)	0.922 (− 0.47)
D_Amendment	0.976 (− 0.11)	1.248 (0.45)	1.008 (0.04)
D_Withdrawal	0.605 (− 0.76)	–	0.488 (− 1.13)
D_Termination	1.262 (1.11)	0.477 (− 0.81)	1.139 (0.66)
D_Duration	0.776 (− 1.08)	3.079*** (2.64)	1.021 (0.14)
D_Denunciation	1.579 (1.62)	–	1.09 (0.33)

*, **, and *** denote significance at the 0.1, .05 and .01 level, respectively (two-tailed test). Figures in parentheses are *z* statistics. All models are Cox proportional hazard. Values greater than 1 indicate higher risk and those less than one indicate lower risk. Standard errors are clustered by treaty. All models include climate zone fixed-effects. – denotes that the model did not produce a result. Each result reported in the table was produced in a separate model

Table 4 The sources of water treaty change by number of parties, 1950–2004

	(1) *Amend* bilateral	(2) *Amend* multilateral	(3) *Renegotiate* bilateral	(4) *Renegotiate* multilateral
Dispute Settlement Mechanism	0.534*** (− 2.62)	0.459* (− 1.71)	0.637** (− 2.16)	0.411* (− 1.80)
Militarized Interstate Dispute	0.742 (− 0.49)	1.959* (1.65)	0.817 (− 0.36)	2.079* (1.77)
Up/Down Stream	0.932 (− 0.23)	0.753 (− 0.58)	0.972 (− 0.10)	0.563 (− 1.38)
Past Change	4.956*** (7.56)	2.867*** (4.75)	4.079*** (9.26)	2.835*** (4.89)
Agreement Age	1.023** (2.24)	0.989 (− 0.66)	1.021*** (2.61)	1.000 (− 0.03)
Wald χ^2	115.52***	82.19***	152.95***	118.00***
N (*Treaties*)	108	36	108	36
NT (*Treaties*× *Year*)	3321	853	3321	853

Regression models for treaty replacement are excluded because the number of such treaties is too small to produce meaningful statistical results when split to bilateral and multilateral treaties

Figures in parentheses are *t* statistics. All models are Cox proportional hazard. Values greater than 1 indicate higher risk and those less than one indicate lower risk. Standard errors are clustered by treaty. All models include climate zone fixed-effects

*$p < 0.1$, **$p < 0.05$, ***$p < 0.01$

Table 5 List of treaties that changed by amendment or replacement

Treaty name	Year signed	Type of change
US Canada Diversion Niagara River	1950	Amended
UK Uganda Egypt Meteorological and Hydrological Surveys Nile Basin	1950	Amended
Luxembourg Germany Power-Plant Sauer	1950	Amended
Douro Amend Convention 1927	1951	Amended and replaced
US-Canada St. Lawrence Seaway	1952	Amended
Syria Jordan Yarmuk	1953	Replaced
India Nepal Kosi Project	1954	Amended
Peru Bolivia Puno-Guaqui Railway Lake Titicaca	1955	Amended
Protocol Lake Inari	1956	Replaced
Committee for Co-ordination of Investigations Lower Mekong Basin	1957	Amended and replaced
France Spain Lake Lanoux	1958	Amended
Argentina Paraguay Apipe Falls	1958	Amended
UAR Sudan full utilization of the Nile waters	1959	Amended
Treaty Columbia River Basin	1961	Amended
Exchange of Notes Meuse	1961	Amended
Lake Geneva Pollution	1962	Amended
Brazil Uruguay Joint Commission Mirim Lagoon	1963	Amended and replaced
Central African Power Corporation	1963	Replaced
Convention of Bamako	1963	Amended
Protocol Commission Rhine Pollution	1963	Amended
Niger River Commission	1964	Amended and replaced
Convention Development Chad Basin	1964	Amended
International Boundary and Water Commission USA-Mexico	1965	Amended and replaced
South Africa Portugal Zambesi River	1967	Amended and replaced
Spain Portugal Guadiana	1968	Amended
Treaty of the River Plata Basin	1969	Amended
Switzerland Italy Breggia	1970	Amended
Peru Ecuador Development Puyango-Tumbes	1971	Amended
US-Canada Great Lakes water quality	1972	Amended and replaced
US-Canada Committee on Water Quality St. John	1972	Replaced
Brazil Paraguay Salto Grande de Sete Quedas	1973	Amended
Bangladesh India Ganges Farakka	1977	Amended and replaced
Organization for the Management and Development Kagera River Basin	1977	Amended
Gambia River Basin Development Organization	1978	Amended
Recommendations for the Solution to the Border Sanitation Problems	1979	Amended
South Africa Swaziland Mozambique Tripartite Technical Committee	1983	Amended
US Mexico Protection of Environment	1983	Amended
Brazil Bolivia Cachuela Esperanza Hydroelectric Plant	1984	Amended
South Africa Lesotho Highlands Water Project	1986	Amended
International Commission Elbe	1990	Amended
Uruguay Brazil Cuareim River	1991	Amended
Joint Management Utilization Aral Sea	1992	Amended
Convention Lake Victoria Fisheries Organization	1994	Amended

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