An empirical analysis of participation in international environmental agreements*

Francesco S. Bellelli†, Riccardo Scarpa‡, Ashar Aftab§

20th November 2021

Abstract

This study investigates the determinants of participation in environmental agreements. To this end, we collated the largest ratification dataset in the literature. Unlike previous data sets, ours includes both global and regional agreements and identifies all countries eligible for membership in each agreement. This allows us to correct an identification bias affecting previous empirical estimates. We improve upon past unobserved heterogeneity by using a multilevel survival approach and Markov Chain Monte Carlo (MCMC) estimator. Our findings show that countries' participation choices are interrelated and primarily driven by the agreement's characteristics. We also find that the quality of institutions and environmental lobbying positively affects participation in environmental agreements, while the effect of industrial lobbying is statistically insignificant. This result is robust to changes in specification and proxies used. Our results motivate several policy suggestions. We emphasise regional agreements' capacity to deliver higher participation than global agreements and highlight the importance of securing the early participation of key players.

Keywords: International environmental agreements, ratification, lobbying, regional agreements, international cooperation.

JEL codes: Q58, F53, D72, C23, C41.

*The authors are grateful to Thomas Renstrom, Alexandre Sauquet, Laura Marsiliani and Hong Il Yoo for comments on earlier versions of this work. This paper has not been submitted elsewhere in identical or similar form. The authors declare that they have no conflict of interest.

†Corresponding author. Dr. Bellelli (e-mail: f.s.bellelli@dunelm.org.uk, phone: +44 7908382857): Centre for Environmental and Energy Economics, Durham University Business School, University of Durham, Durham DH1 3LB, United Kingdom.

‡Prof. Scarpa (e-mail: riccardo.scarpa@durham.ac.uk): University of Durham, Durham, United Kingdom; University of Waikato, Hamilton, New Zealand; University of Verona, Verona, Italy

§Dr. Aftab (e-mail: ashar.aftab@durham.ac.uk): University of Durham, Durham, United Kingdom.

1 Introduction

International cooperation is required to solve some of the most severe environmental problems of our times. Air pollution, contamination of lakes and rivers, global warming, biodiversity loss, deforestation, desertification, and over-fishing are all problems that cross national borders and simultaneously affect several nations. In these cases, no single policymaker possesses the power to enforce environmental policies in all concerned countries. This decentralisation of power calls for a horizontal approach based on cooperation (Barrett, 2005). In theory, there is a clear incentive to cooperate since total welfare increases when environmental issues are addressed multilaterally (Carraro & Siniscalco, 1998). However, cooperation is not guaranteed because there are also incentives to free ride when no central authority can enforce an international agreement (Barrett, 2008).

International environmental agreements (IEAs) are the primary cooperative tool to solve such transboundary issues. To date, there are more than three thousand bilateral and multilateral environmental agreements (Mitchell, 2017) in force. However, our understanding of their dynamics is limited. So far, participation in environmental agreements has mainly been studied with game-theoretical modelling, and it has remained relatively under-explored from an empirical perspective (Finus et al., 2017).

This study aims to provide a better understanding of the drivers of participation in environmental agreements. To this end, we collated a new data set on ratification of environmental agreements which identifies the potential ratifiers for each agreement. This characteristic allows us to study the determinants of participation in regional environmental agreements and solve an identification bias that had affected previous results in the literature. Moreover, this study contributes to the economic literature by introducing a modelling strategy and estimation technique that is more robust to unobserved heterogeneity than previous methods. This is also the first large-sample study looking at the effect of domestic interest groups on participation. This line of enquiry is a direct response to the recent developments in the theoretical literature that emphasise the domestic choice-making process of treaty participation (e.g. Habla & Winkler, 2013; Marchiori et al., 2017; Battaglini & Harstad, 2020; Hagen et al., 2021).

In the next section, we briefly introduce our new ratification data set. Section 3 looks at the existing literature on environmental agreement participation. Then, in section 4, we outline our theoretical framework and empirical approach. In section 5, we report the analysis' results and use them to simulate the ratification probabilities of agreements. We conclude the paper by listing a few stylised facts and discussing the policy implications of our findings. For the interested reader, we provide two supplementary online appendices documenting our data and reporting the full results of our robustness and convergence checks.

2 A new data set to study participation in environmental agreements

Participation in an agreement is fundamental for its success because international agreements are only binding for participating countries. Participation in an agreement generally involves two stages: the *signature* followed by the *ratification*[5]. Our data set and the rest of our analysis will focus on ratification because this is the step that formally commits a nation, whereas signature entails no obligations.

We analyse ratification with a newly collated data set comprising 263 multilateral environmental agreements and 198 countries between 1950 and 2017. We make this data set available online for future research. Our data tracks the ratification decisions for almost 20,000 treaty-country dyads. It is one of the largest data sets applied in this field of research; the only one of comparable size is the data set assembled by Bernauer et al. (2010). Their data set was used in several studies of environmental treaty ratification, such as Bernauer et al. (2013b), Böhmelt et al. (2015), Spilker & Koubi (2016), Hugh-Jones et al. (2018) and Koubi et al. (2020). Nonetheless, it has important limitations that our data collation sought to overcome.

Table 1: *Ratification data sets*

Data set	Treaties	Countries	Years	Regional treaties
Our data set	263	198	1950–2017	Yes
Bernauer et al. (2010)	255	180	1950–2000	No
Leinaweaver (2012)	55	193	1980–2010	Yes
Schulze & Tosun (2013)	21	25	1979–2010	Yes, all
Schulze (2014)	64	21	1971–2003	No
Cazals & Sauquet (2015)	41	99	1976–1999	No

First of all, Bernauer et al. (2010) included many agreements that are not strictly related to the environment, such as those concerning nuclear energy or the Moon Agreement (1979), the Convention on Conditions for Registration of Ships (1986), the Convention on the Law of the Sea (1982), and Disarmament Convention on Biological Weapons (1972)[6]. On the other hand, our sample of treaties includes exclusively agreements directly connected with environmental issues and explicitly mention their environmental scope either in the title or in the text of the treaty.

Our data set's second and arguably most substantial contribution is that it solves an identification problem existing in previous works. Past studies implicitly assumed in their models that all the countries that failed to ratify *could* do so. This works well for universal treaties, but the assumption is violated if regional or less-than-global agreements are included in the studied sample. The centrality of this rather crucial assumption has been gravely overlooked in past works. If not addressed properly, it introduces a bias in the estimates, leading to a systematic underestimation of ratification probabilities.

Not all of the treaties are universal in the data set of Bernauer et al. (2010) (as well

[5]In this study, we use the term ratification to indicate both the act of ratification and accession. Ratification is defined by Art. 2 of the Vienna Convention (1969) as the act "whereby a State establishes on the international plane its consent to be bound by a treaty". For multilateral agreements, the procedure involves the deposition of a ratification document. On the other hand, accession is the act of joining a treaty that has already been negotiated (Art. 2, Vienna Convention, 1969). It has the same value as ratification, and the procedure is established in the agreement's text. Accession often happens for states that did not exist or did not take part in the negotiations.

[6]Cf. the bibliography for the full title of these agreements.

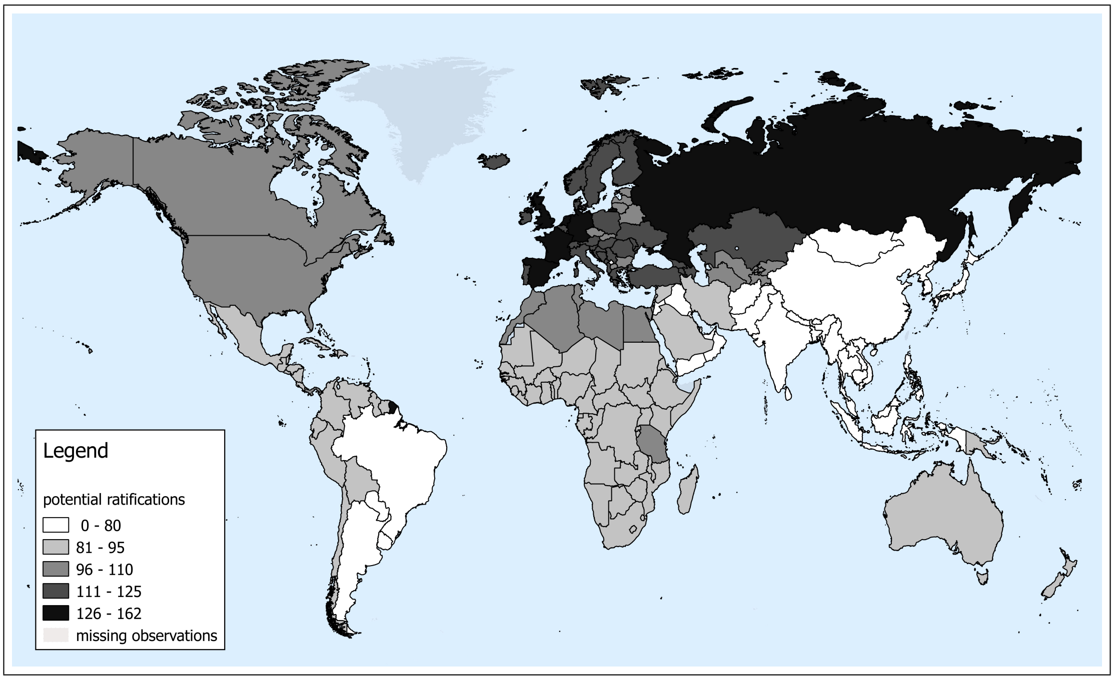

Figure 1: *Potential ratifications by country*

Notes: Not all countries have access to the same number of agreements. The number of agreements ratified by a nation depends on the number of agreements it can potentially ratify.

as in most other major data sets); indeed, some could only be ratified by a subset of countries. We provide two examples of agreements that are in different ways incorrectly included in their data set: *i*) the convention on LRTAP (1979), which is only open to members of the Economic Commission for Europe (UNECE countries) according to Article 15 of the same convention, and *ii*) the Convention for the Protection of the Mediterranean Sea against Pollution (1976), which would not be ratified by distant nations such as Nicaragua or South Korea. Bernauer et al. (2010) are aware that some of the agreements could be *de facto* open just to a restricted number of countries. In the appendix, they decide to run their model on a reduced sub-sample of treaties with no obvious regional nature: the total number of treaties is halved to include only 113 environmental agreements.

We addressed this by identifying for each of the 263 agreements in our data set, all the countries that could potentially ratify, that is, the set of potential ratifying countries. As shown in figure 1, countries differ in their inherent opportunity to ratify agreements, and hence the composition of the "ratifiable agreement" sets differ in size and type across countries. Our identification procedure is based on the scope and text of the agreements. For full reference, we provide a detailed explanation of the data and the criteria used for identifying potential ratifiers in the online data appendix. This feature is fundamental because it allows us to include regional treaties into our analysis. This, in turn, leads to the third limitation of previous works: since most agreements are regional, we may get a distorted picture by looking only at global treaties. Apart from

Leinaweaver (2012), this is the only study covering regional treaties. Management of freshwater resources, protection of habitats and ecosystems, pollution of seas and lakes, etc.. Most environmental issues are geographically narrow and, consequently, involve a limited number of countries. Environmental agreements reflect this aspect; the largest part of the international environmental cooperation is regional (Figure 2).

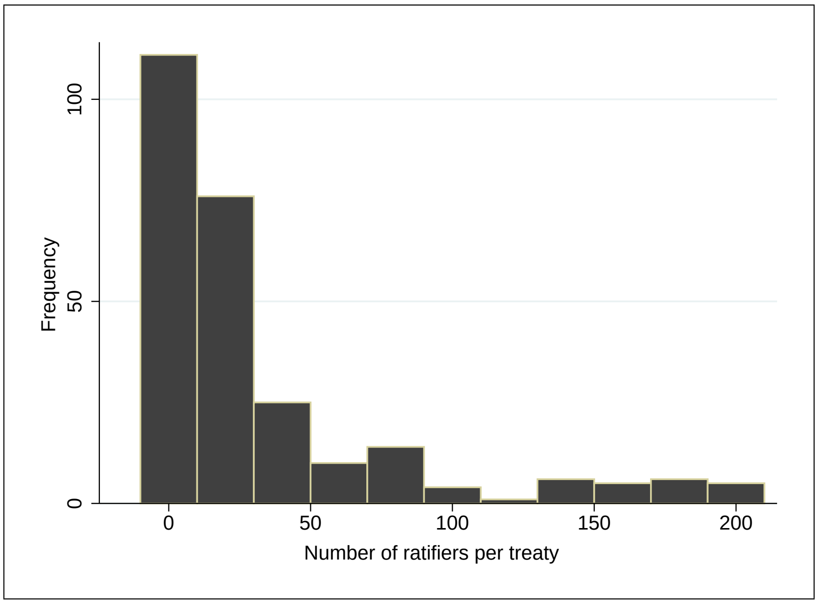

Figure 2: *Number of ratifiers in environmental agreements*

Notes: Most of the agreements have fewer than 50 members. The low number of ratifiers is not the consequence of countries' reluctance to ratify (Fig 4). Instead, it reflects the fact that a large part of environmental cooperation occurs regionally. Hence the relevance of including regional agreements in the analysis.

3 Studies on environmental treaty participation

3.1 Theoretical literature

The prevailing theoretical framework views nations as unitary agents engaged in maximising domestic social welfare. Environmental issues affecting a group of countries can be solved by negotiating and participating in international environmental agreements. However, countries also have an incentive to free-ride on environmental agreements to obtain environmental benefits without paying the costs associated with the agreement (Pearson, 2011). This situation has been extensively treated in game-theoretical models predicting both the optimal treaty abatement and participation levels.

The classic participation game has two stages. In the first stage, countries decide if they want to form (and ratify) an environmental treaty, while in the second stage, countries decide their emission levels. In such models, a country joins the coalition of ratifiers only if doing so is deemed beneficial. Hence, a treaty can only be formed if it is *self-enforcing*—i.e. the incentive structure induces a stable cooperating coalition—but these cases are traditionally deemed rare and do not apply to the most pressing environmental issues (Barrett, 2008). Moreover, participation in environmental agreements is usually assumed to rely on the same criteria used to model cartel stability; thus, the equilibrium is often precarious.

In a synthesis of the main results of the classic participation games, Barrett (1994) states three stylised points about the effectiveness of environmental agreements:

1. Agreements codify commitments that countries would undertake unilaterally even without the agreement;

2. When the number of participants to the agreement is large, the agreement brings few obligations and implies a low abatement effort;

3. International cooperation is harder to attain when it is most needed.

These conclusions constitute the "paradox of cooperation" (Barrett, 1994). The implications for ratification are straightforward: high ratification rates are achieved only when the commitment level is low, whereas stringent agreements should not attract ratification. These dire conclusions originate from the structure of the model. Transboundary environmental issues are analysed with games framed as prisoner's dilemmas, where the Nash equilibrium lies in a non-cooperative solution. Later works have corroborated the trade-off underpinning the paradox, with some improvements in the views expressed in the latest contributions (Finus et al., 2017). For example, if instead of framing the problem as a one-off decision, countries are allowed to participate in different periods, outcomes are generally more encouraging. Higher participation rates are attained in repeated games, especially when communication is allowed or when the treaty is linked to other issues (Bloch & Gomes, 2006; Biancardi & Villani, 2015; Wagner, 2016; Kováč & Schmidt, 2021). An important contribution in this area comes from Harstad (2015) and Battaglini & Harstad (2016). They build a unifying framework to understand treaty participation in a dynamic setting in which countries can invest in green R&D and renegotiate agreements with varying duration. They show that short-term agreements can create significant disincentives to investment in green technologies (investment holdup problem), thus reducing the free-riding problem and increasing participation in the agreement. This could explain why observed coalition sizes are usually larger than what classic participation games imply.

A growing body of literature seeks to incorporate public choice theory within the classic treaty participation game. Public choice theory promotes an endogenous view of policy decisions in which environmental policies are described as the outcome of tensions between different domestic interests. Kirchgässner & Schneider (2003) and Kollmann & Schneider (2010) state that decisions over environmental policies are influenced by the following domestic agents: *i*) electors, *ii*) public institutions and administration, *iii*) interest groups, and *iv*) politicians. A broad body of literature sought to incorporate the tensions between these agents into endogenous models of environmental policy selection. In recent years, this effort has been extended from environmental policies to environmental agreements. So far, research has focused on embedding the effects of lobbying practices (Haffoudhi, 2005; Marchiori et al., 2017; Hagen et al., 2021) and electoral incentives (Habla & Winkler, 2013; Battaglini & Harstad, 2020) into the classic game-theoretical framework of treaty participation. In the lobbying models, environmental and industrial lobbies influence the ratification of environmental agreements through the policymaker's "political support" function. The political interactions are then grafted on a classic non-cooperative two-stage game of environmental agreement participation (Haffoudhi, 2005; Hagen et al., 2021). In other cases, an additional stage is included either to reflect domestic ratification procedures (Köke & Lange, 2017) or to simulate the bargaining among domestic stakeholders (Marchiori et al., 2017). The models suggest that the traditional trade-off of treaty participation could be easily mitigated if there is a sufficient domestic support in favour of ratification. These models offer a more realistic representation of the domestic-international interplay of treaty ratification (à la Putnam, 1988), notably missing in the classic participation literature.

3.2 Empirical literature

To date, much of the empirical research effort has focused on understanding the main drivers of participation in environmental agreements. These factors can be grouped into four main categories: *i*) economic factors that shape incentive to participate and free-ride, such as income or trade openness (Neumayer, 2002b); *ii*) Political factors that influence the ratification process, such as the type of regime and quality of democracy (Congleton, 1992; Schulze, 2014; Cazals & Sauquet, 2015); *iii*) Treaty characteristics, which determine the attractiveness of the treaty and the cost of participation (von Stein, 2008; Bernauer et al., 2013b); *iv*) Country interdependence which mitigates the free-riding incentive (Bernauer et al., 2010; Yamagata et al., 2017). A comprehensive survey of this empirical literature and its methodology can be found in Bellelli et al. (2021). Our discussion here will focus on two topics of interest to this paper: regional agreements and the role of domestic interest groups.

Early empirical literature focused on a handful of large environmental agreements. Before 2010, virtually all empirical studies modelled ratification of either climate change treaties (the UNFCCC or Kyoto Protocol) or Ozone-Depleting Substances agreements (e.g. Vienna Convention or Montreal Protocol). Hence, the evidence of these early studies was specific to a very narrow subset of famous global agreements. A key contribution was made by Bernauer et al. (2010), the first study attempting to model ratification choices by pooling a large number of environmental agreements. Subsequent studies copied this approach (e.g. Leinaweaver, 2012; Böhmelt et al., 2015; Hugh-Jones et al., 2018; Koubi et al., 2020). However, the emphasis remained on large multilateral agreements—even though most environmental cooperation takes place on a regional scale (Mitchell, 2003). So far, regional agreements were either excluded from the sample of these studies or incorrectly incorporated in their analysis. In both cases, results are biased and cannot generalise to the whole population of agreements. We will discuss this point in greater detail in the methodology section.

The role of domestic interest groups has attracted far less attention in empirical studies than in theoretical ones. Only handful of studies have tackled this issue, probably because of data limitations. To the best of our knowledge, the influence of domestic interest groups has been studied empirically for the first time by Fredriksson et al. (2007). In their framework, the ratification decision of a corruptible policymaker considers the welfare gains from improvements in the quality of the environment. However, it is also affected by the contributions, bribes, and pressure of environmental and industry lobbies. Fredriksson et al. (2007) define the corruption level as the intensity of the state's preference for the contributions over gains in social welfare. Given this definition, more

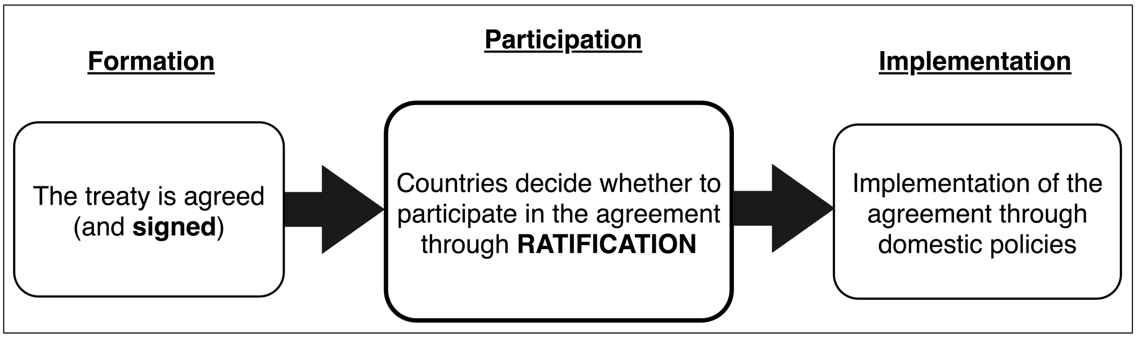

Figure 3: *A model of environmental agreements in three stages*

corrupted governments should be more sensible to lobbying activity. To test their hypotheses empirically, the authors use data on ratification of the Kyoto Protocol by 170 countries. They build two models based on a binary (logit) and a survival dependent variable (Cox PH model stratified for Annex I countries with time measured in days). The results show that the ratification probability increases with environmental lobbying, and the more the government is prone to corruption, the stronger is this effect. Interestingly, the estimates for industrial pressure are not found to be statistically significant. On the other hand, environmental lobbying is consistently found to have a positive impact on the ratification probability. Our paper generalises the analysis of Fredriksson et al. (2007) by extending it to a large sample of environmental agreements and improving the methodological treatment of unobserved heterogeneity.

4 Empirical approach

4.1 Analytical framework

As previously mentioned, the decision to participate in a treaty is implemented in two stages: signature and ratification. We focus on ratification because it is the final and definitive act marking participation in the agreement, whereas the signature stage is costless as it does not entail any formal commitment to ratify and it does not legally bind the country to environmental actions.

We take the model described in Köke & Lange (2017) as a conceptual reference. The model comprises three stages: the first stage corresponds to the formation of the treaty and its signature by a coalition of countries; in the second stage, the coalition members may or may not ratify the agreement[7]; in the third stage, countries implement their environmental policies. Our study aims to evaluate countries' ratification choices corresponding to the second stage of Köke & Lange (2017) model.

Following Almer & Winkler (2010), we assume that a country behaves rationally and ratifies the environmental agreement only if its net expected benefit from ratification, B, is deemed positive ex-ante. The sign of ex-ante net benefit cannot be observed directly, but we postulate it is a function of a series of domestic factors (D), international interactions (I) and treaty characteristics (T). These factors constitute our model's

[7] Köke & Lange (2017) model presumes that only coalition members can ratify. This is not true in reality.

variables and influence either positively or negatively the net benefit of ratification. The ratification choice is presented as follows:

$$Y_{ij} = \begin{cases} 1, & \text{if } B_{ij}\left(D_i, I_{-ij}, T_j\right) > 0 \\ 0, & \text{if } B_{ij}\left(D_i, I_{-ij}, T_j\right) \leq 0 \end{cases} \tag{1}$$

Where $Y_{ij} = 1$ denotes ratification of treaty j by country i, while $Y_{ij} = 0$ if country i does not ratify treaty j. Domestic factors, denoted by D, include the income level, the quality of the environment, and other variables of interest, such as the strength of domestic pressure groups or the quality of institutions. International interactions, I, encompass the influence of foreign nations $(-i)$ on the decision to ratify. The decision by country i is linked to the ratification of other nations with which it shares economic, diplomatic or cultural ties. I is treaty-specific; the ratification of a treaty j by a foreign nation $-i$ affects the net benefit from ratification by nation i solely for treaty j (i.e. agreements are *independent*).

$$B_{ij}\left(D_i, I_{-ij}, T_j | Y_{-i-j} = 1\right) - B_{ij}\left(D_i, I_{-ij}, T_j | Y_{-i-j} = 0\right) = 0, \ \forall -i \text{ and } -j \tag{2}$$

In principle, it is possible to have interrelated ratification choices for groups of environmental agreements. However, this seldom occurs in current theoretical models and linkage is more often modelled across different types of issues (e.g. environment and trade agreements) than two agreements dealing with separate environmental issues. Finally, T encloses those agreement features that influence ratification cost. For instance, it might include whether a treaty is regional or global, the stringency of its obligations, whether it includes transfers for developing countries, or other design features, such as minimum participation rules, the presence of escape clauses or penalties for non-compliance. Since we assume that agreements are independent, the net benefit of ratifying treaty j is only impacted by the characteristics of treaty j.

Assuming that B_{ij} is continuously differentiable in D, I and T, we can derive the marginal effect of variables of interest on the willingness to join the environmental agreement. The marginal effects would be obtained conditional on the variables in B_{ij} and assuming that the agreement j has been negotiated—i.e. we can only observe the agreements that take shape. Thus, our framework specifically answers the question: *Given that an agreement has been agreed, what motivates participation?*

4.2 Empirical model

The analytical framework outlined above can be translated into an empirical model of ratification. We model ratification with a survival analysis approach. This approach allows us to accommodate the time dynamics and deal with the right-censoring problem of observing ongoing ratification processes.

An alternative to survival analysis would be to perform a count analysis of ratification (e.g. Egger et al., 2011; Davies & Naughton, 2014). However, this approach is inappropriate because it fails to answer an important question: what treaty is ratified? After all, not all of the agreements are alike. Each treaty has its own peculiar mix of obligations and economic implications. It is theoretically possible to analyse if a treaty has been ratified at one point in time (i.e. cross-sectionally) with a binary regression, but

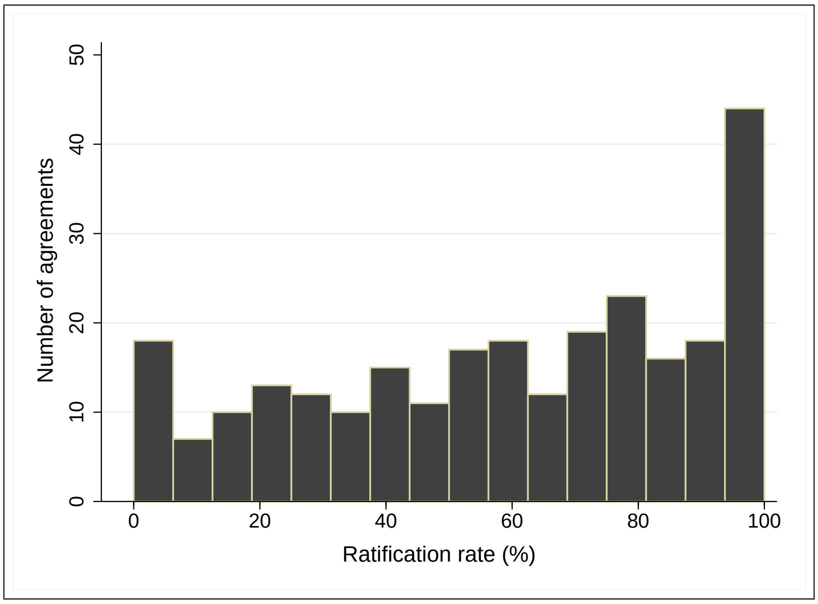

Figure 4: *Ratification rate*

Notes: The figure unveils substantial heterogeneity in the ratification rate of environmental agreements. What factors explain the success or failure of a treaty? We argue that country and treaty characteristics are responsible for this variability. The ratification rate is calculated as the number of ratifiers over potential ratifiers up to 2017.

this approach has important limitations. First of all, whether ratification occurred depends on the point in time chosen to assess it. There is a second and more fundamental reason to consider a time dimension. Ratification is intrinsically dynamic: what matters is not only *if*, but also *when* a country ratified. If we merely focus on the occurrence of ratification, we are ignoring precious information.

Ratification could be affected in two ways: *i*) by changing the final outcome (i.e. whether or not the country ratifies), and *ii*) by delaying ratification. We believe the latter is crucial in understanding the effects of certain variables on ratification. This is especially true for agreements that attracted almost universal ratification. In which case, a strategy based solely on the outcome would fail to capture the heterogeneity across countries[8]. The same applies to smaller agreements that are ratified by almost all of the potential ratifiers. Agreements with high ratification rates represent a substantial share of our sample (figure 4). Finally, timing is also inherently important in understanding the sequence of ratification by different countries. It is impossible to disentangle foreign influence on ratification without a temporal observation of ratification.

In the context of survival data analysis, treaty ratification is defined by two sets of information: whether ratification takes place (outcome) and the time to ratification (duration). For existing countries, the ratification timing starts with the signature of

[8]For example, the UNFCCC (1992) and the Montreal Protocol (1987) both achieved universal ratification with 197 parties. However, ratifications did not occur simultaneously: Canada ratified the UNFCCC in 1992 (soon after signing), France in 1994, Turkey in 2004 and Andorra in 2010. Similarly, the Montreal protocol was ratified in 1992 by Australia, Belgium in 1996, Angola in 2000 and Iraq in 2009.

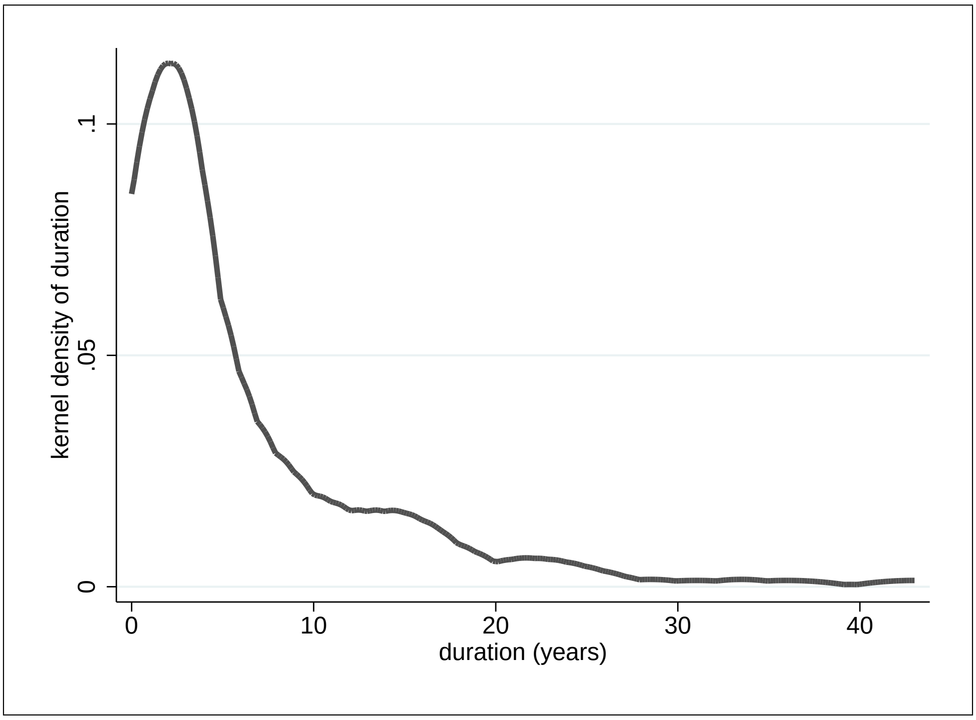

Figure 5: *Kernel density estimates of duration for treaty ratifiers*

Notes: Ratifications tend to concentrate in the ten years following the signature. Some agreements experience more than one wave of ratifications (e.g. Kyoto Protocol), but the chances of being ratified generally decay rapidly with time.

the agreement. This is when the text of the treaty is agreed upon and becomes formally open to ratification. If a country did not exist at the point of signature, the timing starts from the year it came into existence (e.g., by acquiring independence). Each survival spell ends either with ratification or a missed ratification, in which case we have right-censored data (Figure 6). Fortunately, this should not affect our estimates in a survival analysis framework because we can assume independent censoring—the duration of truncated spells depends uniquely on the exogenous year of signature and the fixed observation point. A third case for the end of the survival spell is the extinction of the country itself. In our data set, only a handful of countries experience extinction: East Germany, USSR, Yugoslavia, Czechoslovakia, South Yemen, South Vietnam. Despite the low incidence, extinction is a potential source of bias from competing risk. For this reason, we removed dissolved countries from the risk set. With our data, left-censoring is impossible by definition because the act of signature and ratification is always public, and the observation period is uninterrupted until 2017 (the observation year).

Despite the continuous nature of the ratification process, we group it into yearly observations to match the observation frequency of the explanatory variables. We can handle discrete survival analysis with a binomial regression by considering this data as a series of success/failure trials for which we observe a yearly binary response (Prentice & Gloeckler, 1978). For every country-treaty-year combination, we have a dichotomous response variable that takes the value of 1 if ratification occurred and 0 otherwise. We

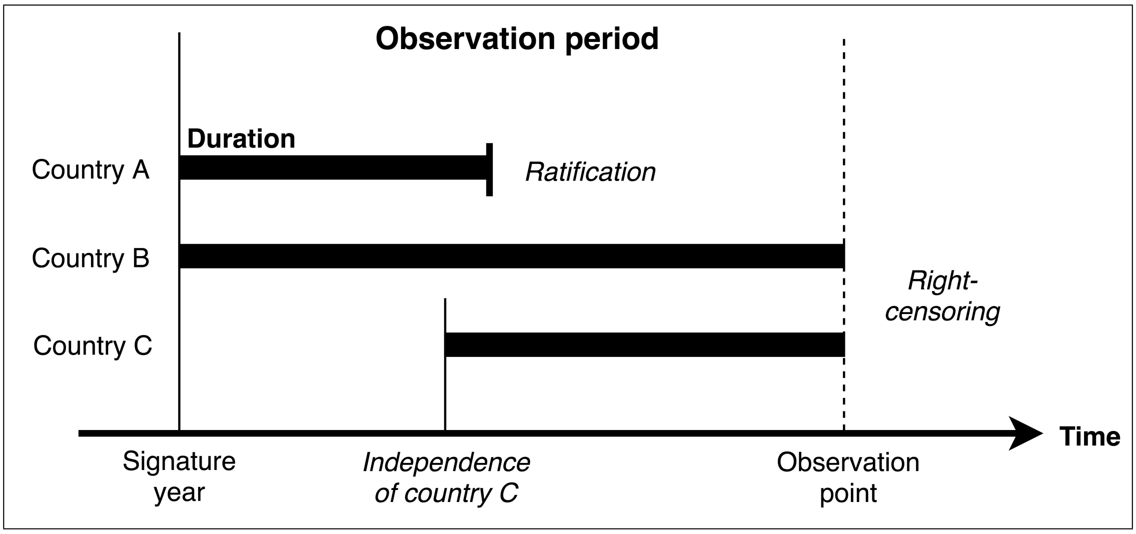

Figure 6: *Censoring in ratification data*

Notes: Survival spells for a representative environmental agreement. The figure also illustrates the difference between the age of the treaty and the concept of duration. The duration is subjective to the country-treaty dyad because the starting points for the survival spells may differ across countries.

define the hazard function $h(t)$ as the probability of observing ratification during the time interval t, *given no earlier ratification*:

$$h_{ij}(t) = \Pr\left(y_{ij}(t) = 1 \mid y_{ij}(t-1) = 0\right) \tag{3}$$

Where y_{ij} and t are respectively the response variable and the duration for every country-treaty combination ij. Time is a discrete variable and the hazard is assumed constant over the time interval. Then, our model has the following form:

$$\text{cloglog}\left[h_{ij}(t)\right] = \alpha(t) + \boldsymbol{D_i(t)\beta} + \boldsymbol{I_{ij}(t-1)\gamma} + \boldsymbol{T_j(t)\lambda} + u_i + u_j \tag{4}$$

$$\alpha(t) = \alpha_0 + \alpha_1 t + \alpha_2 t^2 + \alpha_3 t^3 \tag{5}$$

$$u_i \sim \mathcal{N}(0,\, \sigma^2_{u_i}) \qquad u_j \sim \mathcal{N}(0,\, \sigma^2_{u_j}) \tag{6}$$

Where $\boldsymbol{D}$, $\boldsymbol{I}$ and $\boldsymbol{T}$ are vectors containing domestic, international and treaty explanatory variables, and $\boldsymbol{\beta}$, $\boldsymbol{\gamma}$ and $\boldsymbol{\lambda}$ are their respective vectors of conformable parameters. Unlike some types of survival models, this specification allows the explanatory variables to be time-varying; for this reason, we express them as a function of time. We use one-year lagged indicators for international interactions ($\boldsymbol{I}$) to avoid simultaneity bias. The lagged values of $\boldsymbol{I}$ are not strictly independent since they depend on past values of country's i ratification decisions. However, past ratification status is a given condition in estimating the ratification hazard (equation 3) because it is estimated only for treaty-country dyads that did not already ratify.

The baseline hazard function is denoted by $\alpha(t)$. Following the approach proposed by Carter & Signorino (2010), we model baseline hazard with a cubic polynomial (equation 5). The cubic polynomial specification is also preferred in the existing ratification literature. For instance, Bernauer et al. (2010), Leinaweaver (2012), Böhmelt et al. (2015) and Spilker & Koubi (2016) all use cubic polynomials. It is also possible to use a non-parametric baseline hazard. To ensure the robustness of our results, we estimate also estimate our main model with non-parametric specification in appendix.

The ratification model includes two random-effects to account for the unobserved heterogeneity at both country and treaty levels. Fixed effects are not used in survival analysis because they would perfectly predict non-occurrence in many units (Greene, 2002). If used, the resulting estimates would be based solely on the units that experienced the event and consequently biased. Hence, in the context of survival analysis, unobserved heterogeneity is modelled with frailty terms, which correspond to the inclusion of a random effect. Previous studies did not usually deal with this problem. A common solution consists in using robust standard errors clustered on countries (e.g. Perrin & Bernauer, 2010; Böhmelt et al., 2015; Koubi et al., 2020). The problem is that observations are not only clustered on countries, but also on treaties. That is, not only are the ratifications of treaty A and treaty B by France correlated, but also the Russian and French ratifications of treaty A will not be entirely independent. The use of robust standard errors can alleviate the problems linked to the correlation of units, but it fails to correct the bias deriving from unobserved heterogeneity. This is particularly serious in the case of environmental agreements because ratification depends on numerous and unmeasurable agreement characteristics. Notably, ratification is very likely to be affected by the stringency of the agreement—as pointed out by the "depth vs participation" trade-off widely discussed in the game-theoretical literature. Moreover, for longer durations, the risk set will increasingly consist of dyads with low risk of ratification. These will participate in the estimation of the baseline hazard and, if we do not control for unobserved heterogeneity, they could tend to accentuate the effect of negative factors on the length of duration and understate the effect of positive factors.

In equation 4, the complementary log-log link function is preferred over a logit or probit function because it approximates a standard survival model with grouped observations. Prentice & Gloeckler (1978) demonstrate that the coefficients of a continuous proportional hazards model with grouped data are identical to those obtained from a discrete binary regression using the *cloglog* link function. In addition, the results obtained from a complementary log-log link function can be interpreted in terms of hazard ratios, which is more intuitive than the odds of hazard.

4.3 Model variables

We introduce the variables included in the domestic characteristics ($\boldsymbol{D}$), international interactions ($\boldsymbol{I}$) and treaty characteristics ($\boldsymbol{T}$) of equation 4. These have been chosen based on the the main determinants identified in the theoretical and empirical participation literature. For ease of reference, Table 2 summarises the explanatory variables in our model and provides information on data sources.

Main variables

Recent theoretical models depict ratification choices as the outcome of conflicting in-

Table 2: *Definitions and sources*

Variables	Variable definitions and sources
ENGO	Number of ENGOs memberships to the International Union for the Conservation of Nature by country in 2017. Data from IUCN website (IUCN, 2017a). We assume a constant value over the entire time period because no panel data is available. In the appendix, we perform robustness checks with other time-varying proxies for environmental lobbying.
ResourceRent	Sum of fossil fuels (gas, coal, oil, mineral and forest) rent as percentage of GDP, where rents are the difference between the average production cost and commodity price. It captures the extent of monopolistic power in the fossil fuel industry — which we assume correlates with industrial lobbying potential. Data from the WDI dataset (World Bank, 2017a).
Institutions	Control of Corruption indicator from the World Governance Indicators (World Bank, 2017b). Expressed in units of a standard normal distribution.
$ENGO \times Institutions$	Interaction term between *ENGO* and *Institutions*
$ResourceRent \times Instit$	Interaction term between *ResourceRent* and *Institutions*
logIncome	Natural logarithm of the GDP per capita in current USD. Data from the UN National account estimates (UNSD, 2017a).
CivilLiberties	Freedom House index of civil liberties. On a scale from 1 to 7, where a lower score indicates greater freedom. Data from Freedom House (2017).
ThreatenedSpecies	Based on the Red List Index, an index of the conservation status of species groups in a territory. A higher risk of extinction is associated with lower scores. Data from IUCN website (IUCN, 2017b).
logForest	Natural logarithm of the forest area expressed in thousands of squared kilometres (FAO, 2017).
RatRegion	Share of countries in the same M49 sub-region (UNSD, 2017b) that ratified the agreement.
RatUS	Dummy variable that takes the value of 1 if the United States already ratified the agreement.
RatChina	Dummy variable that takes the value of 1 if China already ratified the agreement.
RatRussia	Dummy variable that takes the value of 1 if Russia already ratified the agreement.
RatIndia	Dummy variable that takes the value of 1 if India already ratified the agreement.
RatGermany	Dummy variable that takes the value of 1 if Germany already ratified the agreement. Since EU countries tend to ratify en bloc, we use this as a proxy for EU ratification. The results do not differ if we take France as our proxy.

Variable definitions and sources (continued)

Variables	Definitions and sources
Regional	Dummy variable taking the value of 1 if the treaty is not open to all countries or if the scope of the agreement is regional (e.g. a treaty on the protection of a river basin or EU environmental agreements). The variable has been coded based on the agreement's text as reported in the IEA Database Mitchell (2017). More information on how the treaties are coded can be found in the online data appendix.
FrameworkAgreement	Dummy variable that takes the value of 1 if the agreement is a framework agreement according to the lineage classification of Mitchell (2017).
t	Duration: number of years the treaty-country combination has spent in the risk set.

terests within the country (Habla & Winkler, 2013; Marchiori et al., 2017; Köke & Lange, 2017; Lui, 2018). For this reason, it makes sense to analyse the effect on ratification of the two opposing tensions within the country: the *environmental* (supporting ratification) and *industrial* lobbying (opposing ratification). Industrial and environmental lobbying are proxied by the variables $ENGO$ and $ResourceRent$. These are, respectively, the number of environmental NGOs of the country and the sum of fossil fuel rents as a percentage of GDP. To ensure that our results are robust, we test four additional proxies for industrial lobbying and two more proxies for environmental lobbying.

Previous theoretical and empirical studies have also highlighted that the effect of lobbying may be non-linear. In particular, the theoretical models discussed in section 3, usually assume that the effects of lobbying depend on the policymaker's preference for contributions over social welfare (e.g. Haffoudhi, 2005; Marchiori et al., 2017)—i.e. how corruptible it is. We control for this by including the variable $Institutions$, which is the control of corruption index by World Bank (2017b) and inserting an interaction term between the quality of institutions and environmental/industrial lobbying ($ENGO \times Instit$ and $ResourceRent \times Instit$).

We address international interactions ($\boldsymbol{I}$) between countries' ratifications by including the share of neighbours that already ratified the agreement ($RatRegion$) and a series of dummies for the ratification of key international players ($RatUS$, $RatChina$, $RatRussia$, $RatIndia$ and $RatGermany$ for EU countries). These variables capture the effect of foreign decision on domestic ratification. All foreign ratifications refer to period $t-1$ to avoid simultaneity bias.

Finally, we include the dummy $Regional$, which takes the value of 1 if only a subset of nations are potential ratifiers to the agreement. All else equal, we expect regional agreements to be more likely to be ratified. Barrett (1999) shows that global agreements can only sustain small coalitions, but he argues that a combination of regional agreements can achieve higher participation for the same issue. The same result is obtained by Osmani & Tol (2010) under less stringent assumptions, such as asymmetric payoffs and accounting for different levels of environmental damage.

Other controls

In addition to the variables above, we control for the main determinants identified by the theoretical and empirical literature. We include the logarithm of GDP per capita and its squared value to account for the relationship with income and any inverted bell-shaped relationship as suggested by some previous works (Bernauer et al., 2010; Sauquet, 2014; Böhmelt et al., 2015; Koubi et al., 2020) in analogy with the Environmental Kuznet Curve. We also control for the quality of democracy with the index *CivilLiberties*; democracy has consistently been linked to higher probabilities of ratifying (Congleton, 1992; Fredriksson & Gaston, 2000; Neumayer, 2002a). This should also ensure the results we obtain for *Institutions* are isolated from the democratic quality of governments. We control for the state of the environment with *ThreatenedSpecies*, an index on species conservation. We choose this proxy over the more popular air pollutant emissions (e.g. Leinaweaver, 2012; Spilker & Koubi, 2016; Hugh-Jones et al., 2018) because it captures a broader set of human impacts on the environment. Temperature change, habitat disruption, water pollution, poaching, desertification, air pollution and/or deforestation all have a devastating impact on animal habitat. Moreover, we include the logarithm of forest area (*logForest*) to account for the country's natural capital endowment. Countries that are rich in environmental assets might engage more often in environmental cooperation and receive stronger international pressure to ratify. Lastly, we include a dummy (*FrameworkAgreement*) to distinguish framework agreements from protocols, which might have more stringent obligations. Other unobserved treaty characteristics are captured by the treaty frailty term.

4.4 Model estimation

Because of the multilevel structure and binary dependent variables, the likelihood of the observed data does not have a closed-form expression. Therefore estimation methods involve approximation. Some of the most popular methods are quasi-likelihood (such as Goldstein & Rasbash 1996 or Breslow & Clayton 1993), Laplace approximation, adaptive quadrature, and Markov chain Monte Carlo (MCMC).

This type of model can be fitted through iterative algorithms based on generalised least squares (e.g. IGLS or RIGLS) giving quasi-likelihood estimates obtained by alternating between random and fixed parts until convergence is reached. Marginal quasi-likelihood (MQL) and Penalized (or predictive) Quasi-Likelihood (PQL) are applicable even though they tend to perform worse with dichotomous variables (Browne & Draper, 2002) and convergence is harder to reach with larger data sets (Capanu et al., 2013). Another common alternative is the use of Laplacian approximation. However, because of the low variation in survival data and the complex structure of random effects, this type of estimation takes a very long time on large data sets, and convergence is seldom reached. Compared to maximum likelihood methods, MCMC improves estimation precision at the cost of estimation time (Ng et al., 2006). Browne & Draper (2002) demonstrated that for multilevel cross-classified binary regressions, the results are more precise when estimated with MCMC than quasi-likelihood methods. MQL and PQL have a notorious tendency to bias the variance components downwards (Browne & Draper, 2002). Furthermore, MCMC performs well even when the normality assumptions of the random effects are violated.

We decide to estimate the model using the MCMC estimator because of its robustness properties. It can be applied to the binary cross-classified model by using the

Metropolis-Hasting algorithm (Hastings, 1970) as a sampler. This Bayesian simulation method estimates the complete distribution of the parameters. We also prefer MCMC because alternative estimation methods often fail to converge for complex models and large survival data sets like ours, which characteristically have low variability in the dependent variable. Furthermore, with uniform priors and large samples, MCMC yields asymptotically equivalent estimates to MLE (Steele et al., 2004). This property is derived from the Bernstein-von Mises theorem, which states that with large-enough samples, the samples' information dominates the influence of the prior and the posterior distribution is asymptotically equal to a normal distribution centred upon the maximum likelihood estimate (Nickl, 2013). The main downside of MCMC is its very long estimation time. We estimate our model with MLwiN (Charlton et al., 2017), a software developed specifically to deal with large and complex multilevel models maintained by the Centre for Multilevel Modelling of the University of Bristol.

We start the estimation procedure by first fitting a simplified hierarchical model with a quasi-likelihood method (MQL procedure). This should accelerate the convergence of the Markow chains by providing good initial values for the parameters. The following diffuse priors are used in the MCMC analysis:

$$\Pr(\boldsymbol{\alpha}) \propto 1 \qquad \Pr(\boldsymbol{\beta}, \boldsymbol{\gamma}, \boldsymbol{\lambda}) \propto 1 \tag{7}$$

Where $\boldsymbol{\alpha} = \{\alpha_0, \alpha_1, \alpha_2, \alpha_3\}$ are the coefficients of the baseline hazard and $\boldsymbol{\beta}, \boldsymbol{\gamma}, \boldsymbol{\lambda}$ are the coefficients of the independent variables of the model. For the variance parameters, we use the following priors, which correspond to a uniform prior for the logarithm of the variance.

$$\Pr(\sigma_{u_i}) \propto \boldsymbol{\Gamma^{-1}}(\varepsilon, \varepsilon) \qquad \Pr(\sigma_{u_j}) \propto \boldsymbol{\Gamma^{-1}}(\varepsilon, \varepsilon) \qquad \varepsilon = 10^{-3} \tag{8}$$

We simulate as many iterations as needed to guarantee the convergence of the series and reliable inference from the posterior distribution. We run no less than 500,000 iterations. The convergence to the target distribution is evaluated through several tests and measures reported in the appendix. To accelerate the convergence rate and improve the efficiency of MCMC estimation, we use orthogonal reparametrisation. Browne et al. (2009) document how this reparametrisation affects the mixing and convergence time in estimating cross-classified multilevel survival models. Application to our data seems to corroborate their thesis: the number of independent samples obtained with this technique increases, and we notice a general improvement in the mixing of the Markov chains. Orthogonal reparameterisation involves a substitution of the model's parameters with an orthogonal vector of predictors that are then used for estimation. These new parameters have the advantage of facilitating sampling by reducing the correlation between variables. The initial set is then retrieved at the end of the estimation (see Browne, 2017).

5 Results

We report our main results in Table 3. Five different model specifications are presented (Model I to V). The first two are the study's reference specifications; the estimates correspond to the mean of the marginal posterior distributions, which are also presented

Table 3: *Main results on ratification*

	Model I			Model II			Model III		Model IV		Model V	
	H.R.	Mean	S.E.	H.R.	Mean	S.E.	Mean	S.E.	Mean	S.E.	Mean	S.E.
ENGO	1.021	0.021***	(0.006)	1.016	0.016***	(0.005)	0.022***	(0.006)	0.024***	(0.005)	0.022***	(0.006)
ResourceRent	1.004	0.004	(0.004)	1.001	0.001	(0.002)	0.003	(0.004)	0.002	(0.002)	0.000	(0.004)
Institutions	1.103	0.098**	(0.050)	1.080	0.077**	(0.044)	0.167***	(0.046)	0.073**	(0.043)	0.143***	(0.056)
$ENGO \times Institutions$	0.992	-0.008**	(0.004)				-0.011***	(0.004)			-0.009**	(0.004)
$ResourceRent \times Instit$	1.003	0.003	(0.003)				0.003	(0.003)			0.000	(0.003)
logIncome	1.230	0.207*	(0.153)	1.239	0.214*	(0.154)			0.250*	(0.152)	0.244*	(0.170)
$logIncome^2$	0.989	-0.011	(0.010)	0.988	-0.012	(0.010)			-0.016*	(0.010)	-0.012	(0.011)
AnnexI							0.496***	(0.119)				
CivilLiberties	0.879	-0.129***	(0.019)	0.879	-0.129***	(0.020)			-0.122***	(0.019)	-0.102***	(0.022)
ThreatenedSpecies	1.804	0.590*	(0.442)	1.659	0.506	(0.444)	-0.252	(0.457)	0.534	(0.440)	0.352	(0.456)
logForest	1.057	0.055***	(0.015)	1.055	0.054***	(0.016)	0.038***	(0.015)			0.057***	(0.016)
RatRegion	1.804	0.590***	(0.063)	1.809	0.593***	(0.063)	0.582***	(0.062)	0.797***	(0.059)	0.727***	(0.072)
RatUS	0.490	-0.714***	(0.069)	0.490	-0.713***	(0.069)	-0.724***	(0.068)			-0.831***	(0.076)
RatChina	1.435	0.361***	(0.058)	1.432	0.359***	(0.058)	0.365***	(0.058)			0.183***	(0.061)
RatRussia	0.820	-0.199*	(0.134)	0.820	-0.198*	(0.133)	-0.197*	(0.134)			-0.241**	(0.134)
RatIndia	1.289	0.254***	(0.057)	1.285	0.251***	(0.058)	0.246***	(0.058)			0.086*	(0.061)
RatGermany	1.384	0.325***	(0.053)	1.384	0.325***	(0.053)	0.317***	(0.053)			0.529***	(0.063)
Regional	2.370	0.863***	(0.234)	1.091	0.0874	(0.231)	0.89***	(0.235)				
FrameworkAgreement	1.186	0.171	(0.226)	1.164	0.152	(0.220)	0.140	(0.226)	0.077	(0.228)	-0.168	(0.464)
t	1.042	0.041***	(0.010)	1.043	0.042***	(0.010)	0.048***	(0.009)	0.079***	(0.008)	0.087***	(0.012)
t^2	0.994	-0.006***	(0.000)	0.994	-0.006***	(0.000)	-0.006***	(0.000)	-0.007***	(0.000)	-0.007***	(0.001)
t^3	1.000	0.000***	(0.000)	1.000	0.000***	(0.000)	0.000***	(0.000)	0.000***	(0.000)	0.000***	(0.000)
cons		-5.564***	(0.818)		-5.547***	(0.822)	-4.471***	(0.476)	-4.813***	(0.794)	-5.837***	(0.922)
Random part												
Variance *treaty* level		2.584	(0.305)		2.593	(0.305)	2.625	(0.310)	2.884	(0.331)	3.397	(0.661)
Variance *country* level		0.239	(0.030)		0.248	(0.031)	0.237	(0.030)	0.256	(0.032)	0.249	(0.033)
Units: *treaty*		257			257		257		258		72 global treaties	
Units: *country*		190			190		190		192		190	
Obs: *ratification*		219266			219266		219510		231200		179723	
DIC:		56000.05			55996.29		56074.71		57073.16		33557.32	
Burnin:		200000			200000		200000		100000		150000	
Chain Length:		250000			250000		250000		200000		200000	
Thinning:		2			2		2		2		2	

Notes: ***, ** and * indicate one-tailed Bayesian p-values respectively lower than 0.01, 0.05 and 0.10. For models I and II, hazard ratios are provided.

in terms of hazard ratios[9]. The only difference between models I and II is that the latter does not have an interaction term between the quality of institutions and the lobbying variables. Model V is identical to model I but estimated on a sub-sample composed exclusively of global environmental agreements. In Model III the income and democracy variables are replaced with a different proxy for the level of economic development, and Model IV is a simplified specification of model I. All models are estimated with MCMC by performing almost one million iterations per model.

5.1 Regional agreements and treaty characteristics

Figure 7 provides a good summary of our ratification models. The mean survival probabilities of every treaty in the data set are plotted along with the general population mean. Some lines are interrupted before reaching 50 years because they correspond to more recent agreements, which are right-censored at the observation date. The figure shows that a hypothetical average treaty has approximately a 50% chance of being eventually ratified. Nevertheless, participation upturn varies widely among treaties. The random part of the model shows that most of the variation is explained by heterogeneity at the treaty level, which greatly exceeds the impact of unobserved country characteristics (roughly eleven times larger). Even after controlling for regional nature of a treaty and whether or not a treaty is a framework agreement, differences among treaties remain the fundamental cause of disparities in ratification. This result is unsurprising; the success or failure of a treaty depends chiefly on the agreement's content and only secondarily on the country's characteristics or other strategical interaction. This result also emphasises the importance of accounting for unobserved treaty heterogeneity since we cannot properly measure the agreement's stringency. Future research should attempt to better measure treaty features; to date, this aspect remains under-explored.

Our results highlight that regional agreements regularly attain a higher participation rate than global agreements. The regionality of the agreement is the single most important factor explaining ratification likelihood in our model. On average, the hazard of ratification of a regional agreement is 2.37 times that of a global agreement. This shows that treaties can be a very effective tool to solve regional environmental issues because they can easily engage small groups of countries. On the contrary, the negotiation of global agreements is evidently more arduous. Finding a compromise for a large number of nations is a complex exercise and could end up penalising participation in the agreement or its environmental effectiveness.

Besides the impact of treaty features, Figure 7 also shows how the probability of ratification changes over time. Most ratification decisions take place in the initial ten years. Some simple algebra reveals that in our model, conditional on the other variables,

[9] A hazard ratio higher than 1 indicates an increase in the hazard of ratification, while a hazard ratio between 0 and 1 suggests a reduction in the hazard of ratification. Hazard ratios indicate the relative risk of an event between two groups of reference. For example, in the case of *RatUS*, it compares the hazard for treaty-country-year dyads for which the United States has already ratified the agreement with the ones in which it has not. In the case of continuous variables (e.g. *ENGO* or *ResourceRent*), the comparison is with dyads with a unit increase in the variable.

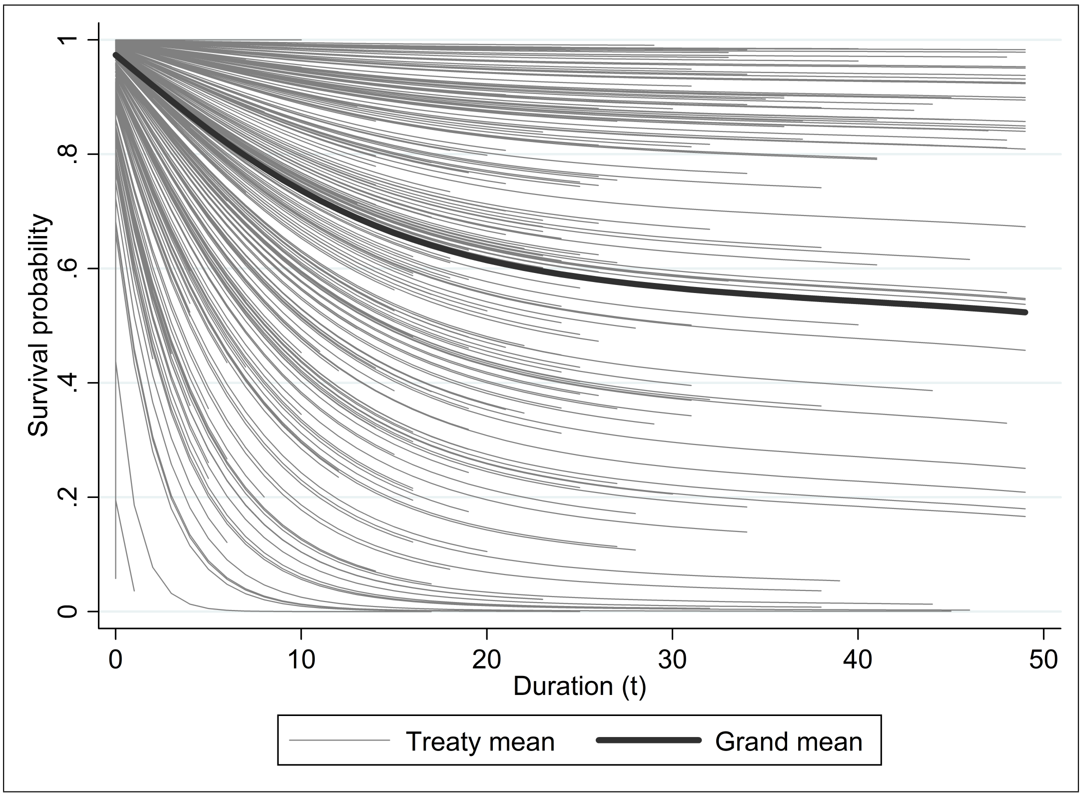

Figure 7: *Survival functions for the environmental agreements*

Notes: The survival functions give the probability that a representative country did not ratify the agreement after t time periods (i.e. "survived" to the agreement). All survival probabilities are calculated by keeping the country variables at their mean values.

the maximum hazard of ratification is reached roughly around the end of the third year from the opening to ratification. After that, the likelihood of ratification decreases due to the "cooling down" of the treaty. This behaviour fits well with the ratification timings observed across most environmental agreements.

The ratification of environmental agreements are affected by multiple unobserved factors. In Figure 8, we rank the countries and treaties according to their individual random effect. The figure illustrates how countries and treaties differ in their propensity to ratification after accounting for all the observed covariates. For example, Norway and the United States are at the two opposite ends of the distribution. At parity of income, lobbying and other control variables, Norway would be significantly more likely to ratify an environmental agreement than the United States. This difference is explained by country-specific cultural, economic and social factors unaccounted for by variables in our model. As we already discussed, the individual unobserved characteristics play an even larger role among treaties. Many agreements located on the left side of the distribution have a large confidence interval. This is because they are open to a smaller number of potential ratifiers and have a low variance in the ratification outcome. For example, the Convention on civil liability for damage resulting from activities dangerous to the environment (1993) is a regional agreement open to a restricted number of countries[10]

[10] According to article 32 of the Convention, the "Convention shall be open for signature by the member

and, to date, it has yet to be ratified by any of its potential ratifiers.

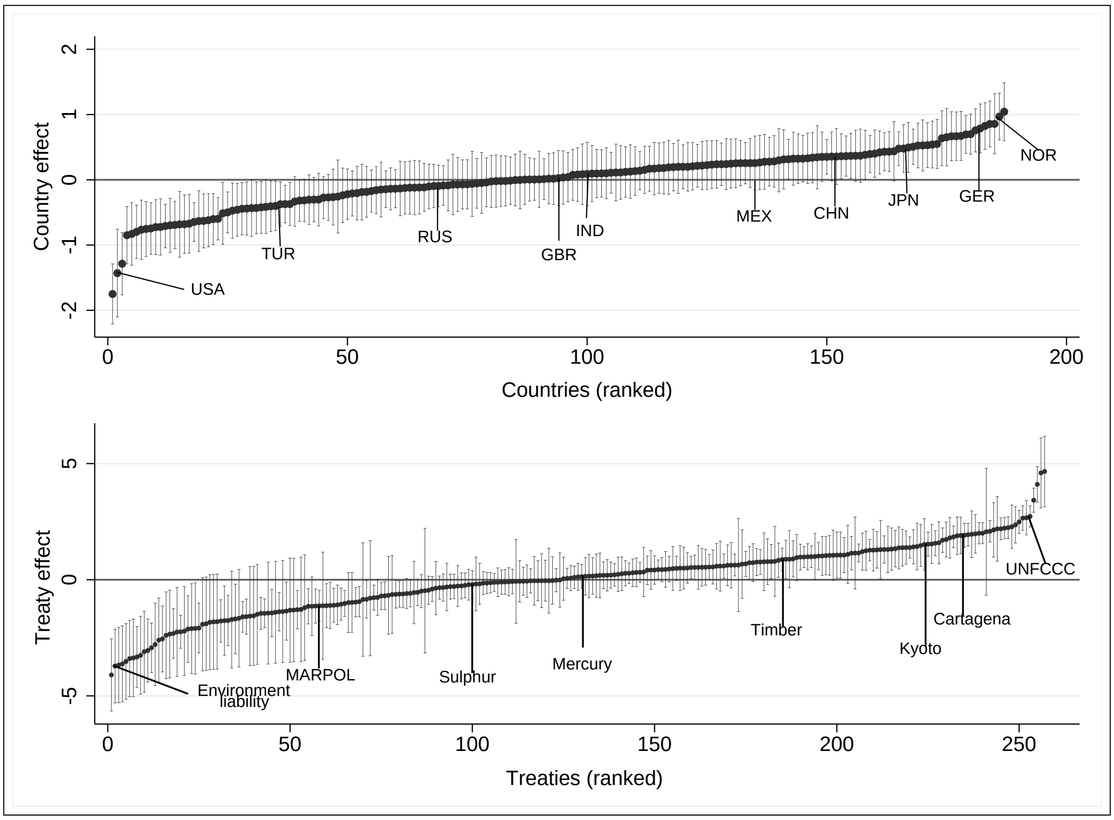

Figure 8: *Caterpillar plots for the treaty and country effects*

Notes & legend: Mean country and treaty effects plotted with their 95% confidence interval. Some countries and treaties have been highlighted as examples. For the caterpillar plot of the treaty effect: **UNFCCC** – United Nations Framework Convention on Climate Change (1992). **Cartagena** – Cartagena Protocol on Biosafety to the Convention on Biological Diversity (2000). **Kyoto** – Kyoto Protocol to the United Nations Framework Convention on Climate Change (1997). **Timber** – International Tropical Timber Agreement (2006). **Mercury** – Minamata Convention on Mercury (2013). **Sulphur** – Protocol to the 1979 Convention on Long-Range Transboundary Air Pollution (LRTAP) on Further Reduction of Sulphur Emissions (1994). **MARPOL** – International Convention for the Prevention of Pollution from Ships (1973). **Environment liability** – Convention on Civil Liability for Damage Resulting from Activities Dangerous to the Environment (1993).

5.2 Environmental and industrial lobbying

We find that environmental lobbying has a positive and significant effect on the ratification probability. One additional environmental NGO ($ENGO$) increases the hazard of ratifying environmental agreements by 1.6% (Model II), and by 2.1% (model I) if the quality of institutions is at its average[11]. The positive effect of environmental lobby-

States of the Council of Europe, the non-member States which have participated in its elaboration and by the European Economic Community".

[11] In model I, the interpretation of ENGO's coefficient is made in correspondence of $Institutions = 0$. Since the variable $Institutions$ is normalised, the value of zero is also the average quality of institutions.

ing is in line with our hypothesis and other literature results (e.g. Fredriksson et al., 2007; von Stein, 2008; Bernauer et al., 2013a). On the other hand, the results for industrial lobbying contrast with our hypothesis on the impact of lobbying. Industrial lobbying is statistically insignificant across all five specifications of Table 3. This result is puzzling since industrial lobbies often have more economic resources and hence are expected to exercise stronger influence, and in the opposite direction, than environmental groups. These findings contradict our expectations; hence they are investigated in more detail in Table 4, where four different measures for industrial lobbying are tested to verify the robustness of our estimates ($EnergyUse$, $ShareIndustry$, $ResourceRich$, $FossilExports$).

$EnergyUse$ is the per capita energy use measured in kg of oil equivalent. The assumption behind this proxy is that energy-intensive economies have stronger incentives to lobby against environmental regulations. $ShareIndustry$ is the share of manufacture, mining and utilities on GDP at current prices. The weight of industry in the economy is the most common proxy for industrial lobbying in the literature (e.g. von Stein, 2008; Yamagata et al., 2013, 2017). $ResourceRich$ is a dummy variable that takes the value of 1 if natural resources account for at least 20% of its exports or national income according to the IMF (2012). This variable captures the economic reliance upon non-renewable natural resources such as coal, gas, oil and minerals. We assume that richness in these resources correlates with stronger pressure against the ratification of environmental agreements. The last proxy, $FossilExports$, is the share of fossil fuels in the export basket. The fossil industry is chosen because it is one of the most polluting industries. The bigger the share of fossil exports in the export basket, the stronger is industrial lobbies' weight. Again, this measure has been used in previous empirical studies (e.g. Fredriksson et al., 2007; Sauquet, 2014).

The estimates in Table 4 are globally stable, and the coefficient estimates are consistent with those in model I–V. The four different proxies we test in this section yield very inconclusive findings on the impact of industrial lobbying. Just like $ResourceRent$ in Table 3, $EnergyUse$ and $ResourceRich$ are statistically insignificant. On the other hand, for $ShareIndustry$ and $FossilExports$, the models exhibit contrasting results. A higher share of fossil resources in the export basket is linked to *lower* ratification probabilities. In contrast, a higher share of manufacture, mining and utilities in the GDP *increases* the likelihood of ratification. Overall, these results do not provide evidence of a negative impact of industrial lobbying on the ratification of environmental agreements.

The explanation we advance is that stronger industrial lobbying does not translate into lower probabilities of ratification because industrial lobbying practices do not target ratification. We argue that, in general, industrial lobbies might prefer to target the implementation phase rather than actively resisting the ratification of environmental agreements. This thesis seems to be supported by the documented impact of industrial lobbying on different environmental domestic policies (e.g. Fredriksson et al., 2005; Sineviciene et al., 2017; Galeotti et al., 2018).

5.3 Disentangling institutional effect: institutions, income and democracy

The quality of institutions plays an important role in the ratification of environmental agreements. From model II, we estimate that a 1 s.d. increase in the quality of institu-

Table 4: *Industrial lobbying*

	EnergyUse		*ShareIndustry*		*ResourceRich*		*FossilExports*	
	Mean	S.E.	Mean	S.E.	Mean	S.E.	Mean	S.E.
Fixed part								
ENGO	0.021***	(0.006)	0.022***	(0.006)	0.022***	(0.006)	0.017***	(0.006)
EnergyUse	-0.001	(0.001)						
ShareIndustry			0.008***	(0.003)				
ResourceRich					0.095	(0.099)		
FossilExports							-0.003**	(0.001)
Institutions	0.134**	(0.066)	0.100*	(0.073)	0.105**	(0.054)	0.207***	(0.068)
ENGO × *Institutions*	-0.010***	(0.004)	-0.008**	(0.004)	-0.008**	(0.004)	-0.010**	(0.004)
EnergyUse × *Instit*	-0.001	(0.001)						
Shareindustry × *Instit*			0.001	(0.002)				
ResourceRich × *Instit*					0.040	(0.084)		
FossilExports × *Instit*							-0.003**	(0.001)
logIncome	-0.110	(0.183)	0.114	(0.158)	0.189	(0.153)	-0.149	(0.198)
$logIncome^2$	0.010	(0.012)	-0.007	(0.010)	-0.010	(0.010)	0.010	(0.012)
CivilLiberties	-0.125***	(0.021)	-0.140***	(0.020)	-0.129***	(0.019)	-0.108***	(0.025)
ThreatenedSpecies	0.684*	(0.471)	0.493	(0.450)	0.596*	(0.440)	0.890**	(0.488)
logForest	0.031**	(0.017)	0.046***	(0.016)	0.052***	(0.016)	0.045***	(0.018)
RatRegion	0.559***	(0.071)	0.586***	(0.063)	0.586***	(0.063)	0.460***	(0.077)
RatUS	-0.691***	(0.076)	-0.715***	(0.069)	-0.714***	(0.068)	-0.709***	(0.078)
RatChina	0.389***	(0.064)	0.354***	(0.058)	0.361***	(0.057)	0.272***	(0.067)
RatRussia	-0.252**	(0.150)	-0.200*	(0.134)	-0.200*	(0.133)	-0.271**	(0.163)
RatIndia	0.209***	(0.065)	0.250***	(0.057)	0.256***	(0.057)	0.214***	(0.067)
RatGermany	0.336***	(0.058)	0.324***	(0.053)	0.327***	(0.052)	0.329***	(0.059)
Regional	0.866***	(0.227)	0.865***	(0.233)	0.881***	(0.238)	0.757***	(0.239)
t	0.046***	(0.011)	0.044***	(0.010)	0.040***	(0.010)	0.073***	(0.012)
t^2	-0.006***	(0.001)	-0.006***	(0.000)	-0.006***	(0.000)	-0.007***	(0.001)
t^3	0.000***	(0.000)	0.000***	(0.000)	0.000***	(0.000)	0.000***	(0.000)
cons	-4.188***	(0.799)	-5.058***	(0.827)	-5.475***	(0.802)	-4.318***	(1.005)
Random part								
Variance *treaty* level	2.501	(0.297)	2.581	(0.303)	2.575	(0.302)	2.523	(0.314)
Variance *country* level	0.222	(0.033)	0.245	(0.031)	0.239	(0.031)	0.263	(0.039)
Units: *treaty*	256		257		257		253	
Units: *country*	169		190		191		174	
Obs: *ratification*	160139		219136		220454		151602	
DIC:	47969.89		55919.16		56091.86		44496.01	
Burnin:	200000		200000		200000		200000	
Chain Length:	200000		250000		200000		250000	
Thinning:	2		2		2		2	

Notes: ***, ** and * indicate one-tailed Bayesian p-values respectively lower than 0.01, 0.05 and 0.10.

tions leads to an 8% increase in ratification hazard. In addition, Model I indicates that the effect of ENGO's lobbying is stronger when institutions' quality is lower.

Table 5 shows that our measure for institutions' quality exhibits a non-trivial degree of correlation with *logincome* (0.736) and *CivilLiberties* (−0.681). Richer nations tend to have better institutions and be governed by more mature democracies. To ensure that the estimates of *Institutions* are unbiased, in model III we omit both *logIncome* and *FreedomHouse* and replace them with *AnnexI*, which is used as a control for the level of development. *AnnexI* is a dummy variable identifying countries included in the "Annex I" list of the UNFCCC (1992). Annex I countries are the nations that have tighter obligations under climate change agreements. This list of countries corresponds to the economically most developed nations and indicates the level of environmental commitment expected of every nation. A comparison of model I and model III reveals that the difference between the two estimates for *Institutions* is statistically insignificant[12]. Hence, we conclude that the inclusion of *CivilLiberties* and *logIncome* does not affect the consistency of the estimates.

Table 5: *Correlation matrix for country variables in model I*

	1	2	3	4	5	6	7
1. ENGO	1.000						
2. ResourceRent	−0.151	1.000					
3. Institutions	0.173	−0.399	1.000				
4. logIncome	0.127	−0.189	0.736	1.000			
5. CivilLiberties	−0.127	0.490	−0.681	−0.575	1.000		
6. ThreatenedSpecies	−0.100	0.154	0.020	0.025	0.070	1.000	
7. logForest	0.341	0.181	−0.240	−0.218	0.194	0.084	1.000

logIncome is associated with a higher probability of ratification, but only at the 10% significance level. Moreover, we do not find evidence of a non-linear relationship with income. In order to secure higher participation of developing countries, environmental agreements often include facilitating measures, technical assistance, and financial aid to developing nations that decide to take part in the agreement. According to the principle of *common but differentiated responsibilities*, the most developed nations are expected to lead the way in terms of environmental commitments and bear the highest share of

[12] A formal hypothesis test shows that the two estimates are not statistically different.

$$H_0\colon\ \beta^{III} - \beta^{I} = 0$$
$$H_1\colon\ \beta^{III} - \beta^{I} > 0$$

Where β^{III} and β^{I} are the estimates for *Institutions* of model III and I, respectively. The Z score for two coefficients of separate regressions is:

$$Z = \frac{\beta^{III} - \beta^{I}}{\sqrt{SE^2_{\beta^{III}} + SE^2_{\beta^{I}}}} = \frac{0.069}{\sqrt{0.05^2 + 0.048^2}} \approx 0.9955$$

With $\alpha = 0.05$, the p-value is approximately $p \approx 0.159$. The difference between β^{I} and β^{III} is statistically insignificant.

the cost of treaties. All of these measures could explain why the influence of income is not as strong as anticipated.

After controlling for income and quality of institutions, we still find that democratic states tend to engage comparatively more in environmental agreements; a lower score in the *CivilLiberties* index is significantly linked to higher ratification probabilities in all models. These results corroborate the widely ackownoledged relationship between democracy and ratification of environmental agreements (e.g. Congleton, 1992; Neumayer, 2002a; Bernauer et al., 2010).

5.4 International interactions

Besides treaty and domestic characteristics, we find that foreign countries' actions explain an important part of ratification decisions. The game-theoretical literature on participation in environmental agreements emphasises that different countries' decisions are strategically linked. Our findings strongly support this contention. If all geographic neighbours ratify the treaty, the ratification hazard increases by as much as 80% (Model I). Furthermore, the ratification decisions of big countries heavily influence the likelihood of ratification by other nations. In particular, ratifications by China, Germany (a proxy for the EU), or India increase the chances of ratifying a treaty. On the contrary, when Russia or the Unites States ratify, the ratification hazard decreases. These results could be explained by the polarising effect that Russia and the United States have on the world's geopolitical system. Despite the fall of the Soviet Union, both countries still have clearly demarcated areas of mostly mutually exclusive influence. The ratification by one of the two countries highly reduces the ratification likelihood by countries in the opposite area of influence; however, the impact of Russia's ratification is significant just at the 10% level. The opposite is true for large nations such as China or India, which are often pivotal for the success of an international environmental agreement. The ratification by one of these two nations is a strong signal of success for the treaty because China and India are often indispensable in achieving environmental goals. We estimate that China's ratification increases the hazard of ratification by 43% while India's by 29%. European Union also has a leading role in promoting environmental commitment, but the high impact of Germany's ratification can partially be ascribed to the high correlation between European ratifications. After the institution of the European Union, most European countries tend to ratify *en bloc*.

5.5 Convergence and robustness checks

We assess the robustness of the results by checking the fundamental assumptions of the model. All the results mentioned in this section are provided in a supplementary online appendix. To begin with, we run a battery of tests to assess the convergence of the MCMC chains. We report the moments of the marginal distributions, the effective sample size (ESS), Raftery-Lewis statistics and the Brooks-Draper statistic. These statistics suggest that the simulation has generated sufficient independent samples and that the estimator has converged. This is confirmed visually by the traces of the chains and the histograms of the marginal posterior distributions. These traces show that the chains seem to have converged around a mean and explored the joint distribution efficiently. To further test the convergence of the chains, we follow Gelman & Rubin (1992) who suggest starting estimation from several different points to ensure the algorithm explored the entire joint distribution and rule out the possibility of pseudo-convergence. The results of these simulations converge to the same distribution and yield identical results to those presented here.

Estimating multilevel survival models with MCMC notoriously yields highly correlated chains (Browne et al., 2009). For this reason, we opted for a very high number of iterations. In total, we perform almost one million iterations for each model, out of which we discard one of every two samples, for a total of 550,000 generated samples. We then discard the initial 300,000 out of 550,000 samples to ensure the inference is based on a converged chain. The number of iterations has been selected prudently to reduce risks of non-convergence.

We assess the estimates' sensitivity for our main variables in the same way it was done for industrial lobbying. We experiment with two new proxies for environmental lobbying and two more for the quality of institutions. The results corroborate model I's findings. In addition to the four models above, we also re-estimate our model with a different link function and a non-parametric baseline hazard specification. The cubic polynomial seems to be a good approximation of the non-parametric version and does not seem to bias the final results. Finally, the appendix reports the Q-Q plots for the treaty and country effects, as well as a specification of the model without these two effects. We find that the standard errors would be pushed downward by their omission, leading to erroneous conclusions on the parameters' significance. These results validate our modelling choices and highlight the stability of the estimates.

5.6 Simulating ratification probabilities

Our model estimates can be put to several uses. For example, negotiators and researchers of environmental agreements can use them to simulate ratification probabilities from the survival function of the treaty-country combination of interest. In Table 6, we simulate the probability of ratifying two hypothetical agreements for five nations. The first agreement is a *regional protocol*, while the second is a *global framework* agreement. We call regional—as opposed to global—any agreement that is not open to all nations in the world. Regional agreements tend to have higher ratification rates than global ones: our model predicts that, on average, a regional agreement has more than twice the ratification hazard of a global one. Framework agreements are defined here as the first treaty on a specific topic. Framework agreements usually set the goals, scope and principles. Very often, binding actions are incorporated into subsequent protocols. As a result, framework agreements usually obtain higher rates of ratification than protocols.

Table 6 explores how the forecasted ratification probabilities change with time (5 and 10-year horizon) and when neighbouring countries ratify the treaty (all neighbours versus none do so). The model shows that among these five nations there are big differences in the probability of joining treaties. For instance, the United Kingdom is twice as likely to ratify than the United States. The difference in probabilities between these two countries is mostly due to idiosyncratic factors captured by the country effect (Figure 8). The results also show that the likelihood of ratifying a treaty improves greatly when the neighbouring nations decide to join—in the case of the United Kingdom and Brazil, probabilities are boosted by as much as 20 percentage points. This effect alone could greatly contribute to a treaty's success by triggering a "domino effect" whereby foreign

Table 6: *Simulated probabilities for two hypothetical environmental treaties*

	Regional Protocol		Global framework agreement	
	5 years	10 years	no neighbours	all neighbours
United Kingdom	36%	55%	44%	64%
United States	16%	26%	20%	34%
Russia	27%	42%	30%	48%
Turkey	15%	25%	22%	36%
Brazil	44%	65%	46%	67%

Notes: All variables are assumed at the country average for the period 1990-2015. Probabilities of ratifying the regional protocol are given for a period of 5 and 10 years. In the case of the global framework agreement we present the final ratification probability (capped at 30 years) respectively when no other country and all other countries in the same geographic area have ratified.

nations are drawn to a treaty by following the example of leading countries. Finally, designing environmental governance as interlocking regional agreements could also be used to secure higher participation. Our example shows how the probability forecast of ratification for a protocol over ten years reaches approximately that of its underlying framework agreement.

Besides hypothetical treaties, the model could also be applied to generate predictions on actual agreements. Out-of-sample probabilities of ratification can be obtained by plugging-in forecasted values for the variables in the model.

6 Conclusion and policy implications

We briefly summarise our findings in **six stylised facts** about ratification and draw some important conclusions for policy makers.

Our model highlights that **1) treaty characteristics are responsible for a much larger share of ratification heterogeneity than country factors.** This result is intuitive: the main factor determining the success of a treaty is the content of the treaty itself. Specific characteristics of the treaty can influence the ratification rate. For example, we have shown that **2) regional agreements are more than twice as likely to attract ratification than global agreements**. This finding supports the claim by Asheim et al. (2006) and Osmani & Tol (2010)—among others—who argue that a more efficient approach to tackle global environmental issues involves designing a set of interrelated regional agreements instead of a monolithic global treaty. Moreover, by identifying the potential ratifiers to every agreement, our data set also highlights that **3) most of environmental cooperation takes place on a regional scale**. The majority of the existing agreements are not global treaties with high media coverage (e.g. Paris agreement, Montreal Protocol), but rather agreements involving smaller groups of countries and tackling issues that are geographically narrow: e.g. management of shared fisheries and freshwater resources, protection of habitats and ecosystems, pollution of seas and lakes, etc.

Another salient point of the analysis is that **4) countries' ratifications are not**

random; country characteristics clearly play a factor. In particular, we highlight the relevance of institutional variables in determining ratification. Across all specifications, the quality of institutions and democracy consistently affect the likelihood of joining environmental agreements. This result reinforces the findings of the empirical literature (e.g. Neumayer, 2002a; Fredriksson et al., 2007; Bernauer et al., 2013a). Moreover, it shows that the conclusion holds even for a larger sample, on regional agreements, and after correcting for the potential ratifier bias subsisting in previous empirical studies. Differences in income also affect the country's capacity to participate in a treaty; however, the impact is less conspicuous than expected. Not only does the coefficient struggle to reach a significant level, but we also find no evidence of the supposed non-linearity in the relationship with income postulated by some authors (e.g. Egger et al., 2011; Bernauer et al., 2010). We advance two reasons to explain this result. Firstly, many environmental agreements often include special provisions that facilitate participation by developing nations. These provisions mitigate the impact that lower income levels might have on the willingness to join the agreement. Secondly, income levels tend to correlate with the quality of institutions and democracy. Hence, the environmental benefits associated with an increase in income may in part be attributed to improvements in the quality of institutions and political representation. Finally, our findings show that environmental lobbying increases the ratification of environmental agreements, while industrial lobbying does not seem to affect it.

A second reason for the non-randomness and clustering of ratifications is that **5) ratifications are interrelated between nations**. We find that ratifications by other countries in the same geographical region have a strong and significant positive effect on the likelihood of joining the treaty. We estimate that if all geographic neighbours ratify the treaty, the hazard of ratification increases by as much as 80%. Furthermore, we find that the ratification by superpowers and big nations can have a notable effect on other countries' ratification probabilities. Ratification by large countries, like China or India, have tremendous implications for the success of environmental agreements. When one of these two countries ratify, they significantly increase the ratification probability of other nations. This could justify the game-theoretical prediction that considers two probable outcomes for a treaty: either a very low turnout or a "world coalition". This study stresses the importance of securing influential nations' participation, which could play a critical role in the treaty's success. These nations can have a decisive effect in tilting neighbouring nations towards ratification and triggering a "domino effect". In this regard, early ratification is key for the success of a treaty. In fact, **6) the probability of ratification decreases over time**. It is the highest in the first three years of the agreement and decreases precipitously after five years. Hence, symbolic ratifications by big players is most effective in the early stages of the agreement.

This study presents several contributions to the literature on environmental agreements. Firstly, we collated the largest data set in the empirical ratification literature. This is also the first to include both regional and global agreements. This feature makes it more representative of the population of treaties. A unique characteristic of our data set is the identification of the potential ratifiers for every treaty. This allows us to correct the identification bias of previous studies, which resulted in an overestimation of survival probabilities. While survival analysis is not a novelty in the empirical ratification literature (e.g. von Stein, 2008; Bernauer et al., 2010; Sauquet, 2014), it is the first time a multilevel strategy is used to account for unobserved heterogeneity both at the treaty and country level. Moreover, we are the first to use MCMC—a Bayesian estimation technique—to estimate the ratification model. We argue that MCMC is the best-suited estimation method for survival data with low intrinsic variability and models with complex structures. Finally, we also contribute to the empirical literature on the influence of interest groups on ratification choices by providing the first large-sample study of both environmental and industrial lobbying and testing a set of economic hypotheses on their effect.

Future research could tackle some of the remaining limitations of our study. First of all, there is uncertainty surrounding the measurement of some of our variables. In particular, environmental and industrial lobbying are two concepts that are hard to quantify and for which available data is limited and fuzzy. We have tried to mitigate this problem by validating our results with a large number of proxies. Clearly, research would greatly benefit from more complete and accurate data on the activity of interest groups and on treaty characteristics. Secondly, our study is based exclusively on agreements that have taken shape. However, on some occasions, the negotiation of treaties never occurs, or the countries fail to agree on a treaty. In these cases, environmental problems remain unaddressed. Failed cooperation could be investigated in a general study of cooperation over transboundary issues. Lastly, ratification models have so far always assumed independence in the ratification of distinct treaties. However, there could be cases in which agreements are directly linked. For example, two agreements could be substitutes because they deal in contrasting ways with the same issue; hence participation in one of the agreements precludes participation in the other. This situation could exist between countries that fail to agree on a unified course of action or when competing solutions are offered. A set of agreements could also be complementary; for example, environmental regulation could be split over multiple agreements to facilitate negotiation. We believe the assumption of independence is reasonable and describes the general process of ratification well, but there is scope for a deeper inspection and relaxation of this assumption.

References

Almer, C. & Winkler, R. (2010). Strategic behavior in IEAs: When and why countries joined the Kyoto Protocol. *Bern University Discussion Papers*, 14, 1–28. (Available at: https://papers.ssrn.com/sol3/papers.cfm?abstract_id=1549612).

Asheim, G. B., Froyn, C. B., Hovi, J., & Menz, F. C. (2006). Regional versus global cooperation for climate control. *Journal of Environmental Economics and Management*, 51(1), 93–109.

Barrett, S. (1994). Self-enforcing international environmental agreements. *Oxford Economic Papers*, 46, 878–894.

Barrett, S. (1999). A theory of full international cooperation. *Journal of Theoretical Politics*, 11(4), 519–541.

Barrett, S. (2005). The theory of international environmental agreements. In K.-G. Mäler & J. Vincent (Eds.), *Handbook of Environmental Economics; Economywide and International Environmental Issues*, volume 3 chapter 28, (pp. 1458–1515). Amsterdam, The Netherlands: Elsevier; North-Holland.

Barrett, S. (2008). Climate treaties and the imperative of enforcement. *Oxford Review of Economic Policy*, 24(2), 239–258.

Battaglini, M. & Harstad, B. (2016). Participation and duration of environmental agreements. *Journal of Political Economy*, 124(1), 160–204.

Battaglini, M. & Harstad, B. (2020). The political economy of weak treaties. *Journal of Political Economy*, 128(2), 544–590.

Bellelli, F. S., Aftab, A., & Scarpa, R. (2021). The joinining dilemma: A survey of the empirical literature on environmental treaty participation. *Review of Environmental Economics and Policy*. Forthcoming.

Bernauer, T., Böhmelt, T., & Koubi, V. (2013a). Is there a democracy-civil society paradox in global environmental governance. *Global Environmental Politics*, 13(1), 88–107.

Bernauer, T., Kalbhenn, A., Koubi, V., & Spilker, G. (2010). A comparison of international and domestic sources of global governance dynamics. *British Journal of Political Science*, 40, 509–538.

Bernauer, T., Kalbhenn, A., Koubi, V., & Spilker, G. (2013b). Is there a "Depth versus Participation" dilemma in international cooperation. *The Review of International Organizations*, 8, 477–497.

Biancardi, M. & Villani, G. (2015). The effects of R&D investments in international environmental agreements with asymmetric countries. *Chaos, Solitons & Fractals*, 79, 30–39.

Bloch, F. & Gomes, A. (2006). Contracting with externalities and outside options. *Journal of Economic Theory*, 127(1), 172–201.

Böhmelt, T., Bernauer, T., & Koubi, V. (2015). The marginal impact of ENGO in different types of democratic systems. *European Political Science Review*, 7(1), 93–118.

Breslow, N. & Clayton, D. (1993). Approximate inference in generalized linear mixed models. *Journal of the American Statistical Association*, 88(421), 9–25.

Browne, W. (2017). *MCMC estimation in MLwiN, Version 3.01*. Centre for Multilevle Modelling, University of Bristol. (Online version available at: http://www.bristol.ac.uk/cmm/media/software/mlwin/downloads/manuals/3-01/mcmc-web.pdf).

Browne, W., Steele, F., Golalizadeh, M., & Green, M. (2009). The use of simple reparameterizations to improve the efficiency of Markov chain Monte Carlo estimation for multilevel models with applications to discrete time survival models. *Journal of the Royal Statistical Society*, 172(Part 3), 579–598.

Browne, W. J. & Draper, D. (2002). A comparison of Bayesian and likelihood methods for fitting multilevel models. *Bayesian Analysis*, 1(3), 473–514.

Capanu, M., Gönen, M., & Begg, C. (2013). An assessment of estimation methods for generalized linear mixed models with binary outcomes. *Statistics in Medicine*, 32(26), 4550–4566.

Carraro, C. & Siniscalco, D. (1998). International environmental agreements: Incentives and political economy. *European Economic Review*, 42(3-5), 561–572.

Carter, D. & Signorino, C. (2010). Back to the future: Modeling time dependence in binary data. *Political Analysis*, 18(3), 271–292.

Cazals, A. & Sauquet, A. (2015). How do elections affect international cooperation? Evidence from environmental treaty participation. *Public Choice*, 162, 263–285.

Charlton, C., Rasbash, J., Browne, W., Healy, M., & Cameron, B. (2017). MLwiN Version 3.00. *Centre for Multilevel Modelling, University of Bristol.*

Congleton, R. (1992). Political institutions and pollution control. *The Review of Economics and Statistics*, 74(3), 412–421.

Convention for the Protection of the Mediterranean Sea against Pollution (1976). Convention for the Protection of the Mediterranean Sea against Pollution. *UNEP Secretariat.* Barcelona. (Available at: http://wedocs.unep.org/bitstream/id/53143/convention_eng.pdf).

Convention on civil liability for damage resulting from activities dangerous to the environment (1993). Council of Europe, European treaty series - no. 150. *Directorate General Human Rights and Rule of Law.* Lugano. (Available at: https://www.coe.int/en/web/conventions/).

Convention on Conditions for Registration of Ships (1986). United Nations convention on conditions for registration of ships. *Secretariat of the United Nations.* Geneva. (Available at: https://unctad.org/en/publicationslibrary/tdrsconf23_en.pdf).

Convention on the Law of the Sea (1982). United Nations convention on the law of the sea. *Secretariat for Ocean Affairs and the Law of the Sea.* Montego Bay. (Available at: http://www.un.org/Depts/los/convention_agreements/texts/unclos/unclos_e.pdf).

Davies, R. & Naughton, H. (2014). Cooperation in environmental policy: a spatial approach. *International Tax and Public Finance*, 21(5), 923–954.

Disarmament Convention on Biological Weapons (1972). Convention on the Prohibition of the Development, Production and Stockpiling of Bacteriological (Biological) and Toxin Weapons and on their Destruction. *Secretariat of the United Nations.* London, Moscow and Washington. (Available at: https://www.un.org/disarmament/wmd/bio/).

Egger, P., Jeßberger, C., & Larch, M. (2011). Trade and investment liberalization as determinants of multilateral environmental agreement membership. *International Tax and Public Finance*, 18(6), 605–633.

FAO (2017). FAOSTAT database. *United Nations Food and Agriculture Organisation.* (Available at: http://www.fao.org/faostat/en/).

Finus, M., Cooper, P., & Almer, C. (2017). The use of international environmental agreements in transnational environmental protection. *Oxford Economic Papers*, 69(2), 333–344.

Fredriksson, P. & Gaston, N. (2000). Ratification of the 1992 climate change convention: What determines legislative delay? *Public Choice*, 104, 345–368.

Fredriksson, P., Neumayer, E., Damania, R., & Gates, S. (2005). Environmentalism, democracy, and pollution control. *Journal of Environmental Economics and Management*, 49(2), 343–365.

Fredriksson, P., Neumayer, E., & Ujhelyi, G. (2007). Kyoto Protocol cooperation: Does government corruption facilitate environmental lobbying? *Public Choice*, 133, 231–251.

Freedom House (accessed 2017). Freedom House Index on civil liberties and political rights. *Freedom House.* (Available at: https://freedomhouse.org).

Galeotti, M., Rubashkina, Y., Salini, S., & Verdolini, E. (2018). Environmental policy performance and its determinants: Application of a three-level random-intercept model. *Energy Policy*, 116, 134–144.

Gelman, A. & Rubin, D. B. (1992). Inference from iterative simulation using multiple sequences. *Statistical Science*, 7, 457–472.

Goldstein, H. & Rasbash, J. (1996). Improved approximations for multilevel models with binary responses. *Journal of the Royal Statistical Society*, Series A ,159, 505–513.

Greene, W. (2002). The bias of the fixed effects estimator in nonlinear models. *Working papers, New York University*, 02-05. Available from http://people.stern.nyu.edu/wgreene/nonlinearfixedeffects.pdf.

Habla, W. & Winkler, R. (2013). Political influence on non-cooperative international climate policy. *Journal of Environmental Economics and Management*, 66(2), 219–234.

Haffoudhi, H. (2005). Political-support lobbies responses to internatioanl environmental agreements. *Université Paris 1, Cahiers de la Maison des Sciences Économiques*, 53. (Available at: https://halshs.archives-ouvertes.fr/halshs-00195593/document).

Hagen, A., Altamirano-Cabrera, J.-C., & Weikard, H. (2021). National political pressure groups and the stability of international environmental agreements. *International Environmental Agreements: Politics, Law and Economics*, 21, 405–425.

Harstad, B. (2015). Climate contracts: A game of emissions, investments, negotiations, and renegotiations. *Review of Economic Studies*, 79, 1527–1557.

Hastings, W. K. (1970). Monte Carlo sampling methods using Markov chains and their applications. *Biometrika*, 57, 97–109.

Hugh-Jones, D., Milewicz, K., & Ward, H. (2018). Signaling by signature: The weight of international opinion and ratification of treaties by domestic veto players. *Political Science Research and Methods*, 6(1), 15–31.

IMF (2012). Macroeconomic framework for resource-rich countries. *IMF*. (Available at: https://www.imf.org/external/np/pp/eng/2012/082412.pdf).

IUCN (2017a). Members list. *International Union for Conservation of Nature*. (Available at: https://www.iucn.org/about/members/iucn-members).

IUCN (accessed 2017b). Red list index. *International Union for the Conservation of Nature*. (Available at: http://www.iucnredlist.org/about/publication/red-list-index).

Kirchgässner, G. & Schneider, F. (2003). On the political economy of environmental policy. *Public Choice*, 115(3-4), 369–296.

Köke, S. & Lange, A. (2017). Negotiating environmental agreements under ratification constraints. *Journal of Environmental Economics and Management*, 83, 90–106.

Kollmann, A. & Schneider, F. (2010). Why does environmental policy in representative democracies tend to be inadequate? A preliminary public choice analysis. *Sustainability*, 2(12), 3710–3734.

Koubi, V., Mohrenberg, S., & Bernauer, T. (2020). Ratification of multilateral environmental agreements: Civil society access to international institutions. *Journal of Civil Society*, 16.

Kováč, E. & Schmidt, R. C. (2021). A simple dynamic climate cooperation model. *Journal of Public Economics*, 194.

Leinaweaver, J. (2012). Environmental treaty ratification: Treaty design, domestic politics and international incentives. *Working paper*. (available at: https://papers.ssrn.com/sol3/papers.cfm?abstract_id=2035531).

LRTAP (1979). Convention on Long-Range Transboundary Air Pollution. *Secretariat of the Economic Commission for Europe (UNECE)*. Geneva. (Available at: https://www.unece.org/env/lrtap/welcome.html).

Lui, C. (2018). Inducing heterogeneous countries to impose a global pollution tax with trade sanctions: Can lobbies help? *Working paper*. (Available at: http://web.uvic.ca/~chuiying/carbon_tax_sanctions_lui.pdf).

Marchiori, C., Dietz, S., & Tavoni, A. (2017). Domestic politics and the formation of international environmental agreements. *Journal of Environmental Economics and Management*, 81, 115–131.

Mitchell, R. (2003). International environmental agreements: A survey of their feature, formation, and effects. *Annual Review of Environmental and Resources*, 28, 429–461.

Mitchell, R. (2017). International environmental agreements database project (version 2017.1). *IEA Database Project*. (Available at: http://iea.uoregon.edu/).

Montreal Protocol (1987). The Montreal Protocol on Substances that Deplete the Ozone Layer. *UNEP Ozone Secretariat*. Montreal. (Available at: http://ozone.unep.org/en/treaties-anddecisions/montreal-protocol-substances-deplete-ozone-layer).

Moon Agreement (1979). Agreement Governing the Activities of States on the Moon and other Celestial Bodies (Moon Agreement). *Secretariat of the United Nations*. New York. (Available at: http://www.unoosa.org/oosa/).

Neumayer, E. (2002a). Do democracies exhibit stronger environmental commitment? A cross-country analysis. *Journal of Peace Research*, 39(2), 139–164.

Neumayer, E. (2002b). Does trade openness promote multilateral environmental cooperation? *World Economy*, 25(6), 815–832.

Ng, E., Carpenter, J., Goldstein, H., & Rasbash, J. (2006). Estimation in generalised linear mixed models with binary outcomes by simulated maximum likelihood. *Statistical Modelling*, 6, 23–42.

Nickl (2013). Statistical theory. *University of Cambridge, Working Paper*, Version November 27. (Available at: http://www.statslab.cam.ac.uk/~nickl/Site/__files/stat2013.pdf).

Osmani, D. & Tol, R. (2010). The case of two self-enforcing international agreements for environmental protection with asymmetric countries. *Computational Economics*, 36(2), 51–68.

Pearson, C. (2011). *Economics and the Challenge of Global Warming*. Cambridge, United Kingdom: Cambridge University Press.

Perrin, S. & Bernauer, T. (2010). International regime formation revisited: Explaining ratification behaviour with respect to long-range transboundary air pollution agreements in Europe. *European Union Politics*, 11(3), 405–426.

Prentice, R. L. & Gloeckler, L. A. (1978). Regression analysis of grouped survival data with applications to breast cancer data. *Biometrics*, 34, 57–67.

Putnam, R. D. (1988). Diplomacy and domestic politics: The logic of two-level games. *International Organization*, 42(3), 427–460.

Sauquet, A. (2014). Exploring the nature of inter-country interactions in the process of ratifying international environmental agreements: the case of the Kyoto Protocol. *Public Choice*, 159, 141–158.

Schulze, K. (2014). Do parties matter for international environmental cooperation? An analysis of environmental treaty participation by advanced industrialised democracies. *Environmental Politics*, 23(1), 115–139.

Schulze, K. & Tosun, J. (2013). External dimensions of European environmental policy: An analysis of environmental treaty ratification by third states. *European Journal of Political Research*, 52, 581–607.

Sineviciene, L., Sotnyk, I., & Kubatko, O. (2017). Determinants of energy efficiency and energy consumption of Eastern Europe post-communist economies. *Energy & Environment*, 28(8), 870–884.

Spilker, G. & Koubi, V. (2016). The effects of treaty legality and domestic institutional hurdles on environmental treaty ratification. *International Environmental Agreements: Politics, Law and Economics*, 16, 223–238.

Steele, F., Goldstein, H., & Browne, W. (2004). A general multilevel multistate competing risks model for event history data, with an application to a study of contraceptive use dynamics. *Statistical Modelling*, 4, 145–149.

UNFCCC (1992). United Nations Framework Convention on Climate Change. *UNFCCC Secretariat*. Rio de Janeiro. (Available at: http://unfccc.int/essential_background/convention/items/6036.php).

UNSD (2017a). National Accounts Main Aggregates Estimates dataset. *United Nations Statistical Division*. (Available at: http://data.un.org/).

UNSD (2017b). Standard country or area codes for statistical use (M49). *United Nations Statistics Division*. (Available at: https://unstats.un.org/unsd/methodology/m49/).

Vienna Convention (1969). Vienna Convention on the law of treaties. *United Nations Secretariat*. Vienna. (available at: https://treaties.un.org/doc/publication/unts/volume%201155/volume-1155-i-18232-english.pdf).

von Stein, J. (2008). The international law and politics of climate change. *Journal of Conflict Resolution*, 52(2), 243–268.

Wagner, U. (2016). Estimating strategic models of international treaty formation. *Review of Economic Studies*, 83(4), 1741–1778.

World Bank (2017a). World Development Indicators dataset. *The World Bank*. (Available at: https://data.worldbank.org/data-catalog/world-development-indicators).

World Bank (2017b). World Governance Indicators. *The World Bank*. (Available at: http://info.worldbank.org/governance/wgi/index.aspx).

Yamagata, Y., Yang, J., & Galaskiewicz, J. (2013). A contingency theory of policy innovation: How different theories explain the ratification of the UNFCCC and the Kyoto Protocol. *International Environmental Agreements: Politics, Law and Economics*, 13, 251–270.

Yamagata, Y., Yang, J., & Galaskiewicz, J. (2017). State power and diffusion process in the ratification of global environmental treaties, 1981-2008. *International Environmental Agreements: Politics, Law and Economics*, 17(4), 501–529.