The Participation Dilemma: A Survey of the Empirical Literature on International Environmental Agreement Ratification

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Abstract

Several of the most pressing environmental problems involve transboundary issues and can only be solved through international cooperation. Hence, a successful policy response requires a good understanding of international environmental agreements—the primary tool for international cooperation. What motivates participation in environmental agreements, and how can it be increased? These questions have been addressed in economic research, mostly using game-theoretical approaches, in models that predict the optimal emission abatement and participation levels. Our survey focuses on a contiguous body of work: the empirical literature on environmental treaty participation. The scope of this paper is to compile the first detailed survey of the empirical literature on participation in environmental agreements, summarize its findings, and enable better comparison with theoretical predictions.

Keywords: International environmental agreements, ratification, international cooperation, multilateral agreements

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[A]Introduction

Several of the most pressing environmental problems involve transboundary issues. For example, air pollution, contamination of lakes and rivers, global warming, biodiversity loss, deforestation, desertification, and overfishing are all problems that cross national borders. For these types of problems, traditional policy tools are insufficient or inapplicable because of the absence of a central international authority capable of enforcing decisions in all concerned countries. As a result, agreeing on mutual and voluntary restraints between nations is often the only viable solution to address global environmental problems. In a nutshell, transboundary environmental problems can only be solved through international cooperation.

Among the available tools for international cooperation, international agreements are the most promising, at least in principle. In many ways, international agreements are similar to a contract between nations—but with no superior power capable of enforcing the treaty on shirking parties. To date, more than 3,000 international environmental agreements have been identified (Mitchell 2020), embodying cooperation on a wide range of issues (see Figure 1). Some attract universal participation, while others die on the negotiation table. And of those that garner sufficient participation, some are successful, while others fail to achieve their goals. Given the importance of international cooperation for securing environmental well-being, the following questions are of great interest to economists: What motivates participation in environmental agreements, and how can it be increased?

These questions have been the core subject of several economic models, mostly using game-theoretical approaches, that predict the agreement's optimal emission abatement and participation levels. From the perspective of these models, environmental agreements are international public goods that deal with transboundary environmental externalities (Beron, Murdoch, and Vijverberg 2003). Given the non-excludability and non-rivalry of the environmental benefits of the agreement, countries often contend with a considerable incentive to free ride. As a result, the conclusions of classic game-theoretical models are generally pessimistic on the capacity to solve environmental problems beyond the noncooperation level (Carraro and Siniscalco 1993; Barrett 1994). In these models, large participation in agreements can be achieved only with low abatement targets that fall short of the social optimum (Finus 2008). This outlook originates from core assumptions of these models, which frame treaty participation as a one-off noncooperative choice—just like in a prisoner's dilemma.

Later works largely confirmed the free-riding incentive in treaty participation, with some improvement in the outlook for participation (Finus et al. 2017). For example, participation can be improved if participants can offer side transfers (Barrett and Stavins 2003; Barrett 2001; Fuentes-Albero and Rubio 2010). Under the right circumstances, penalties, trade restrictions, minimum participation rules, and permit trading schemes also can boost participation (Rubio and Casino 2005; Carraro, Marchiori, and Oreffice 2009; Karp and Zhao 2010; Harstad 2015). Moreover, in repeated games—which allow countries to join the agreement in different moments—the results are more optimistic than in one-off games (Bloch and Gomes 2006; Biancardi and Villani 2015; Wagner 2016). For example, Battaglini and Harstad (2016) show that a dynamic game of treaty formation with non-contractible green investments and endogenous treaty duration provides an incentive to form a large coalition because free-riding incentives are reduced by the investment hold-up problem, whereby countries abstain from investing in green technologies because they would require more stringent commitments during treaty negotiations . And in the dynamic models of Kováč and Schmidt (2021), more countries participate to avoid renegotiation delays.

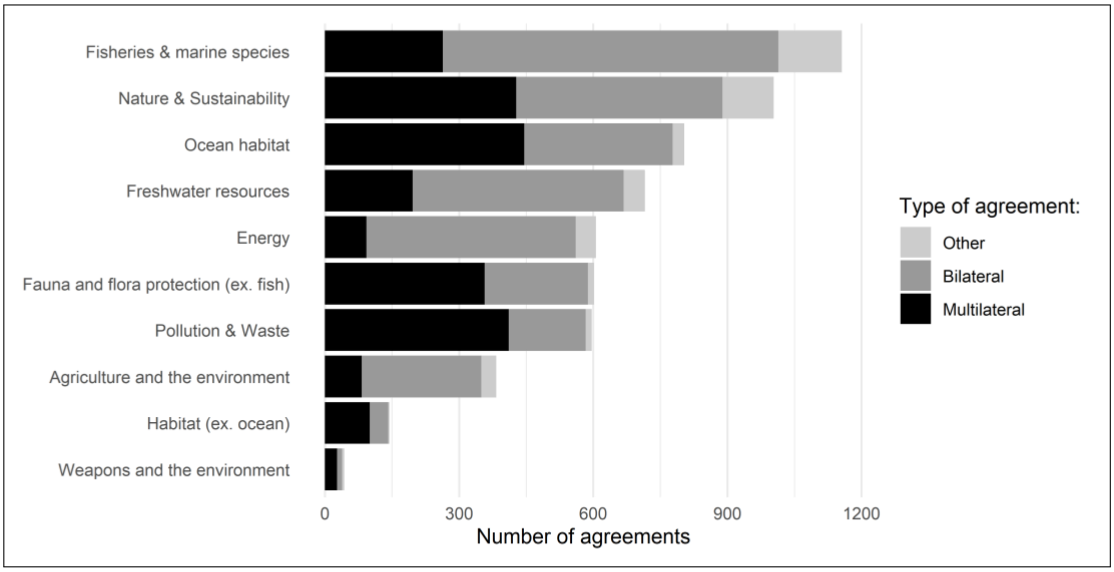

Figure 1 Number of environmental agreements by subject. Bilateral agreements are between two countries. Multilateral agreements involve three or more countries. “Other” types of agreements relate to international organizations and supranational bodies. The existing empirical literature has primarily modeled multilateral agreements. Source: Data from Mitchell (2020).

Interestingly, the empirical research on the determinants of participation in environmental agreements has been developing with little attention from the large body of game-theoretical literature. While the empirical evidence corroborates several of the game-theoretical assertions, it also presents some points of contrast. Given the proximity of this empirical research with game-theoretical models on treaty participation, substantial benefits would arise from their cross-fertilization.

This paper aims to compile a survey of the empirical literature on participation in environmental agreements. This survey answers the following questions: What are the main determinants of participation in environmental agreements, and how can participation be increased? In addition, this survey summarizes the progress achieved so far in the empirical studies and presents their main findings for a more systematic comparison with theoretical predictions. Finally, for interested readers, we supply an online addendum containing a detailed account of the data and techniques used in these studies and highlight each empirical strategy's strengths and limits. While the game-theoretical literature on environmental agreements has been reviewed previously (e.g., Calvo and Rubio 2013; Marrouch and Chaudhuri 2015; Finus et al. 2017), to the best of our knowledge, there is no comprehensive survey of the empirical studies and methods; hence this effort fills a gap in the literature.

Figure 2 Key stages of an international agreement

[A]Lessons from the Empirical Literature on Ratification

The life of an agreement can be divided into three key stages: the formation, participation, and implementation stage (Figure 2). During the formation stage, the delegates of different countries negotiate the terms of the agreement. If the negotiations are successful, they produce an agreement text that national representatives sign. The act of signature is usually carried out by the executive power and signals approval with the agreement's content. Nonetheless, the agreement is not yet effective; implementation requires that the treaties are ratified. Ratification has a legally binding power, and it usually is a prerogative of the nation's legislative body, although rules may change from country to country. Ratification transforms the treaty into a binding contract for the ratifier and marks the decision to participate in the implementation of the agreement. For this reason, the empirical literature has mostly focused on ratification and this article henceforth uses "participation" and "ratification" interchangeably.

A close inspection of international environmental agreements reveals that a ratification process is a complex, intrinsically heterogeneous event. Ratifications refer to the act of participation in treaties that are structured differently, are created by diverse groups of countries under different circumstances, involve various economic agents, and deal with disparate environmental problems on many geographic scales. Nonetheless, some common threads are recurrently linked to ratification. The empirical research has sought to dissect and understand these common threads, with interests ranging from the role of electoral rules and political systems to the incentives provided by trade openness and economic partnership.

We will now survey the main results of the empirical ratification literature by grouping them along the principal determinants of environmental treaty ratification: i) the content of the agreement, ii) the political system of the ratifying country, iii) the economic incentives and disincentives to ratification, and iv) the international interaction between countries. Whenever possible, we compare the empirical findings with the predictions of the game-theoretical literature. Nonetheless, an exhaustive review of the game-theoretical research is beyond the scope of this paper, which focuses on the empirical literature. For a detailed account of the game-theoretical literature on the formation and participation in environmental agreements, the reader can refer to Calvo and Rubio (2013), Marrouch and Chaudhuri (2015) and Finus, Cooper, and Almer (2017). For a more technical review of the data and modeling approaches, we invite the reader to refer to the supplementary online appendix, which also lists all the surveyed studies in three tables providing information about their sample and models.

[B] Treaty Content: Stringency versus Participation

First and foremost, the reason for the success or failure of a treaty is, of course, the content of the treaty itself. Stricter agreements impose higher costs on the parties and, all else equal, should attract fewer ratifications. The empirical research on this subject is not well developed; its main limitation is data availability. These types of studies require data that classifies environmental treaties on their characteristics. At present, the primary sources of information on the ratification of environmental agreements are either the text of the treaties or treaty databases, such as Mitchell (2020) and EXOLEX (IUCN, UNEP & FAO (2013). Unfortunately, neither of these sources has a detailed classification of the characteristics of the agreements. As a result, the studies tend to include either few agreements or a limited number of features. In the second case, achieving objectivity and consistency in the classification of agreements can be difficult: some parameters can be classified clearly, but many elements are more nuanced.

Fundamentally, the research effort has focused on the so-called "depth versus participation trade-off." This phenomenon is well-rooted in the game-theoretical literature on treaty participation (Barrett 1998), in which free-riding incentives dominate the participation choices of countries. In an early analysis of treaty design and participation, von Stein (2008) defines the strictness of environmental agreements based on several characteristics. The main ones are the presence of obligations for the parties, the institution of decision bodies, flexibility mechanisms, and the precision of environmental targets. They conclude that flexibility mechanisms are effective means to facilitate ratification and can mitigate the dissuasive effect of tighter obligations. The problem with this study is that it is based solely on two global treaties on climate change: the UNFCCC (1992) and the Kyoto Protocol (1997). Hence it is hard to generalize the results to environmental agreements as a group.

Leinaweaver (2012) expands the analysis sample to a total of 55 regional and global environmental agreements. According to Leinaweaver (2012), the cost of committing to a treaty is mainly captured by three aspects: the presence of binding obligations, the acceptance of reservations, and the existence of monitoring provisions (very similar to the factors discussed by Bernauer et al. (2010)). Leinaweaver (2012) show that agreements with precise targets and participation thresholds for the entry into force tend to attract more ratifications, supposedly by increasing the credibility of the commitment. This latter result is consistent with the game-theoretical finding that minimum participation rules can be used to enhance the size of stable coalitions in non-cooperative games (Rubio and Casino 2005; Carraro, Marchiori, and Oreffice. 2009).

With a dataset of 200 environmental agreements, Bernauer, Böhmelt, and Koubi (2013) is the largest cross-sectional study on this topic. They argue that "depth" is a complex concept reflected in several design features of an environmental treaty, including the existence of formal obligations for the parties, monitoring, enforcement mechanisms, dispute settlement mechanisms, assistance mechanisms, and organizational apparatus. Their findings indicate that tighter obligations reduce participation in agreements, but, contrary to expectations, stricter monitoring and enforcement do not reduce the likelihood of ratification.

In another large study, Bellelli, Scarpa, and Aftab (2020) compare the ratification of regional and global agreements. One of their main findings is that regional agreements are consistently—and substantially—more likely to attract ratification. Therefore, the authors conclude that it is preferable to frame environmental cooperation through smaller regional interconnected agreements than large global treaties. Again, this result corroborates the conclusion of game theoretical works. For instance, the models of Asheim et al. (2006) and Osmani and Tol (2010) postulate that global agreements can only sustain small coalitions, whereas a combination of regional agreements can achieve higher participation for the same issue. Much of the existing empirical literature has focused on large multilateral environmental agreements. However, most international cooperation occurs on a smaller scale, either regionally or bilaterally (see Figure 1). Future research should investigate these types of agreements in more detail.

Finally, Spilker and Koubi (2016) consider different treaty designs and control for internal voting requirements to approve ratification. Their data is derived from Bernauer et al. (2010) and adopts similar definitions to Bernauer, Böhmelt, and Koubi (2013) to measure environmental agreements' strictness. Their results strengthen the idea that stricter agreements deter participation. They also find that treaties that grant financial or technical assistance to developing countries have a higher chance of being ratified (Spilker and Koubi 2016). This result echoes Mohrenberg, Koubi, and Bernauer (2016), who observe that the institution or participation of a fund in the treaty reduces commitment costs and increases the likelihood of ratification. These findings reinforce theoretical predictions on the size of coalitions when countries are allowed to offer side payments (Barrett 2001; Barrett and Stavins,2003; Fuentes-Albero and Rubio 2010).

Altogether, the findings confirm that more stringent environmental agreements induce free-riding. However, empirical evidence also suggests that some treaty features (e.g., monitoring and enforcement rules, minimum participation rules, technological transfers, and financial assistance) have the property of increasing the abatement level of the treaty without deterring participation (Bernauer, Böhmelt, and Koubi 2013). These results could be useful to frame more efficient environmental agreements. Given the patchy nature of existing results, we believe there is scope for further empirical research on the impact of treaty design on participation and abatement levels.

Finally, it should also be noted that all the empirical studies implicitly assumed that the ratification of a given treaty is independent of the ratification of other treaties. However, agreements could be directly linked with others in some cases. 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 subsist between countries disagreeing on a unified course of action or when competing solutions are offered. A set of agreements could also have complementary ratifications. For example, ratification of some agreements may require a country to join some other agreement or framework convention (e.g., ratifiers of the Kyoto Protocol need to have first ratified the UNFCCC). We believe the assumption of independence is reasonable in most cases; however, there is scope for a deeper inspection of this assumption. Future research could investigate connections between environmental agreements and how they influence participation.

[B]Political System

We have talked about the difference in participation *between treaties*. However, participation in environmental agreements also varies *between countries*. Figure 3 shows that these differences are not random; rather, they seem clustered geographically, suggesting that country characteristics also play a role in treaty participation. Economists study the effect of these country characteristics by regressing these variables on measures of treaty participation. Early studies tended to use as a dependent variable the number of treaties ratified by each country. Then the dominant approach shifted toward using a survival analysis approach—i.e., modeling the expected time to ratification. The advantage of survival analysis is that it incorporates information about the occurrence of ratification (did the country ratify the treaty?) as well as the timing (how long did it take to ratify?). Moreover, its estimates are robust to right-censoring—i.e., the fact that certain ratifications are not observed because they occur after the observation period.

These models have been used to test several hypotheses on the effect of country characteristics on ratification probabilities. To start with, the ratification of environmental treaties is the outcome of a political decision. Therefore, a common thesis is that the political and institutional arrangements have a bearing on their ratification behavior.

[C]The role of democracy

The early literature has emphasized the role of political factors in treaty participation (e.g., Congleton 1992; Neumayer 2002a). According to Neumayer (2002a) and Bernauer et al. (2010), citizens of democratic states can exert more effective political pressure on governments thanks to well-functioning civil liberties, increasing the likelihood that democratic nations will join international environmental treaties.

These ideas have their root in the endogenous model of environmental policy selection by Congleton (1992). In this model, decisions in democracies depend on the electoral behavior of the median voter, whereas in authoritarian regimes, they are assumed to depend on the dictator's vote or the median voter of the ruling oligarchy. All other agents or pressure groups are ignored. Moreover, the model setup assumes that authoritarian states have a higher equilibrium price for emission abatement than democracies. Consequently, it predicts that authoritarian states are less likely to implement environmental policies and participate in environmental agreements.

The relationship Congleton (1992) introduced has been extensively tested empirically. Congleton (1992) formally tests his hypothesis using data from two treaties on ozone-depleting substances; he finds that democracies are more likely to ratify when compared to autocratic nations. Neumayer (2002a) explores the link between democracy and environmental commitment in four environmental agreements (Kyoto Protocol, Montreal Protocol, Rotterdam Convention, Cartagena Protocol on Biosefety) , measured by ratification and other indicators, also finding that democracies tend to engage in environmental agreements more consistently than do non-democracies. A similar result regarding democracies is found by Fredriksson and Gaston (2000), who focus on the speed of

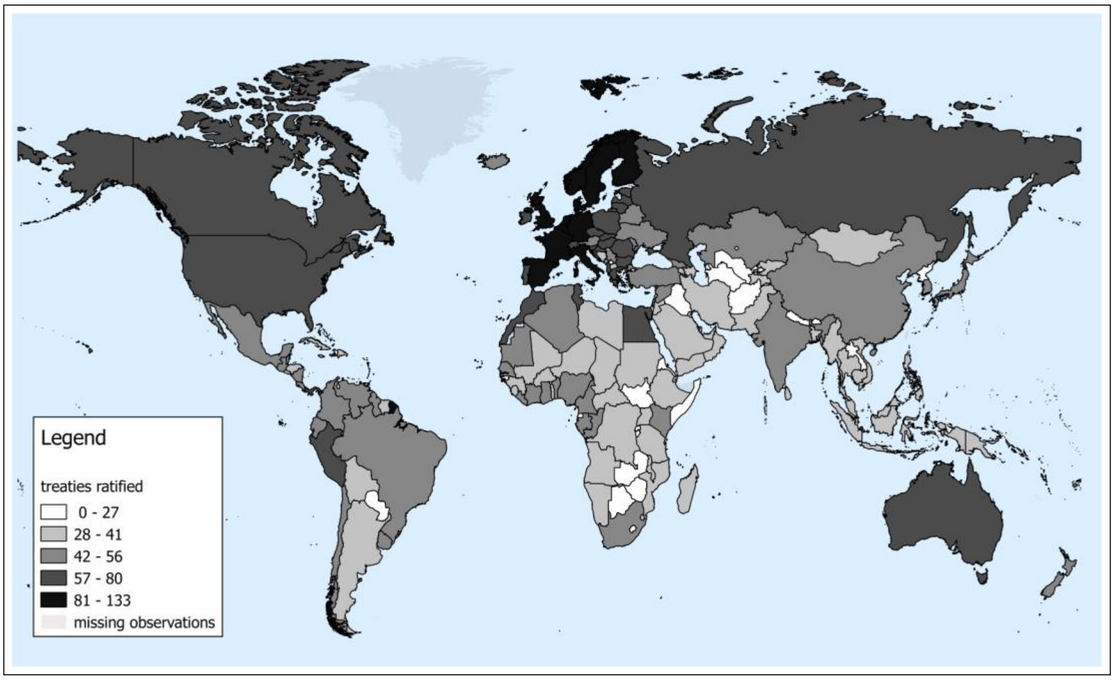

Figure 3 Number of multilateral environmental agreements ratified by country. Treaty ratification data from Mitchell (2020). The mapped sample includes only multilateral environmental agreements (no bilateral agreements) signed in the period 1950–2017.

ratification of the UNFCCC. They find that civil liberties and carbon dioxide emissions are strong determinants of ratification delay. In all such studies that followed, with no exception, researchers have systematically controlled for the democratic characteristics of states and found it to be positively related with ratification (e.g., von Stein 2008; Perrin and Bernauer 2010; Seelarbokus 2014; Mohrenberg, Koubi, and Bernauer 2016; Hugh-Jones, Milewicz, and Ward 2018). The most common measures for democratic government forms are the two indices by Freedom House (n.d) and Marshall et al. (2016).

[C]Electoral dynamics and veto players

The process leading to ratification often goes through several institutional bodies within the state. In most cases, ratifications require the parliament's approval, but some countries consent ratification by the head of government (e.g., Israel and Bangladesh). As a result, the ratification of agreements may depend on multiple veto players—i.e., entities that have the power to block the ratification approval either as an individual (e.g., head of state) or as a group of individuals (e.g., upper house of parliament). For example, Hugh-Jones, Milewicz and Ward (2018) find that the higher the number of veto players in a country, the less likely a country is to ratify the Kyoto Protocol. On a similar note, Spilker and Koubi (2016) assess whether parliamentary voting rules affect the ratification decisions of the country. The study is conducted on a large sample of 220 treaties and 162 countries originally assembled by Bernauer et al. (2010) and focuses on whether constitutional requirements for a supermajority—instead of a simple majority—affect ratification probability. The results support the idea that stricter agreements deter participation and that nations with constitutions requiring a supermajority vote by the parliament are less likely to ratify because they make the internal approval process significantly harder.

Besides constitutional rules for ratification, electoral systems also may play a role in ratification. For example, in a sample covering 75 democracies and 250 treaties from 1973 to 2002, Böhmelt, Bernauer, and Koubi (2015) find that, on average, presidential systems with majoritarian voting provide more public goods and ratify more environmental agreements than parliamentary systems with proportional voting. Cortez and Gutmann (2017) obtain contrasting results from a sample of treaties that includes several non-environmental agreements. These studies are inspired by the influential work of Persson and Tabellini (2003) and Persson, Roland, and Tabellini (2007), which highlight the link between constitutional features, such as electoral systems (majoritarian vs proportional) or political systems (parliamentary or presidential), and their impact on the provision of public goods and other economic outcomes.

Ratification timing also has been linked to election cycles. According to Cazals and Sauquet (2015), electors value attention to the environment. Hence, political leaders should display stronger environmental commitment before elections. To test the connection between electoral cycles, income levels, and ratification timing, Cazals and Sauquet (2015) use a survival model with time measured daily to distinguish the pre- and post-electoral period. Their findings show that developing countries tend to ratify shortly before elections to boost electoral results. In contrast, developed countries tend to ratify soon after elections. Their sample covers the ratification of 41 global environmental agreements by 99 nations from 1976 to 1999. The time coverage is limited by the availability of consistent electoral data. Hence, the results might not accurately extend to the 2020s, given the geopolitical changes and shifts in the public's opinion regarding environmental concerns over the last twenty years.

[B]Economic Factors

In this section, we explore the economic motivations for ratifying environmental agreements. According to the prevailing framework of analysis, the economic characteristics of a country define its interest in ratification and free-riding on the agreement. The main economic drivers for ratification are the income level, activity of interest groups, and free-riding incentives of the country.

[C]Income

Income is a prominent factor influencing the participation of countries in environmental agreements. Statistically, income correlates positively with treaty ratification (see Table 1). The argument invoked to explain this relationship is the controversial Environmental

Kuznets Curve (EKC) hypothesis, which describes a bell-shaped relationship between the degradation of the environment—as measured by emissions of certain pollutants—and the level of per capita income (Cole 2004). The theory behind the EKC postulates that at higher levels of income, countries express a stronger preference for environmental improvements (Stern 2017). Conversely, a country with a low income level might give comparatively more weight to economic development. Given that environmental agreements are a necessary condition for resolving transboundary environmental issues, a higher level of income should be associated with a higher likelihood of ratification (Bernauer et al. 2010).

Table 1 Ratification rate by development status

Development status	Ratification rate (avg.)
High-income countries	57.4%
Developing countries	42.9%
Land-locked developing countries	31.9%
Least-developed countries	35.7%
Small island developing states	40.7%
Other developing countries	50.53%

Notes: Ratification rate is the proportion of treaties ratified over all treaties open for ratification to the country. Data on ratification rates comes from Bellelli, Scarpa, and Aftab (2020). Classification of countries' development level follows United Nations' M49 standard country groupings.

Negotiators of environmental treaties recognize the relevance of income differences. To reduce the effect of income, developing nations often push for systems that mitigate the costs borne by less developed countries, arguing that they face other more urgent priorities, such as the eradication of poverty and sustainable economic development (Hecht and Tirpak 1995). Mechanisms such as economic and technical transfers, flexible deadlines, or less stringent objectives are examples of clauses that aim to mitigate the impact of income on participation in treaties. Despite these facilitating clauses, income levels still play a decisive role in ratification choices. Several studies confirm that richer nations tend to participate in more environmental agreements than less economically developed ones (e.g., Egger, Jeßberger, and Larch 2011; Seelarbokus 2014; Davies and Naughton 2014).

Roberts (1996) stresses that developing nations are less likely to ratify environmental agreements because of their fragile institutions and lack of infrastructures inherited from their colonial past. Roberts, Parks, and Vasquez (2004) further explore this thesis, positing that extractive colonialism leads to a narrow base of exports that make countries more dependent on natural resources and less likely to ratify environmental agreements. However, both studies are cross-sectional and cannot account for treaty characteristics nor control for unobserved country factors.

[C]Interest groups

Putnam (1988) and Barrett (1998) conceptualize ratification as the outcome of a two-stage game. The first stage is played internationally during the negotiation phase of treaties by national representatives; the second stage occurs domestically and is led by political institutions and interest groups. Within this framework, ratification decisions boil down to the contrast between domestic actors, which can be divided into environmental and industrial pressure groups.

Fredriksson, Neumayer, and Ujhelyi (2007) build a two-stage game in which firms and environmental lobbies affect ratifications through campaign contributions, bribes, and media pressure. The implications of this model are tested empirically with data on the ratification of the Kyoto Protocol. They find that environmental lobbying, as proxied by the number of environmental NGOs, is a significant determinant of ratification (a result also found in Böhmelt, Bernauer, and Koubi 2015), while industrial lobbying is insignificantly linked to a lower ratification probability. This result is studied more in detail by Bellelli, Scarpa, and Aftab (2020), who generalize the findings on a sample of 258 agreements and identify the potential ratifiers for every environmental agreement in the sample. All other large-sample ratification studies implicitly assumed that all countries were potentially capable of ratifying every agreement. This misidentification of potential ratifiers leads to ratification probabilities that are biased downward whenever regional agreements are included in the data sample. The results of the study confirm that environmental lobbying has a positive effect on participation in environmental agreements, while industrial lobbying is statistically insignificant. This result is robust to changes in specification and proxies used. The authors advance an explanation based on the lobbying preferences of environmental and industrial interest groups, whereby the latter prefer to target the implementation phase of treaties.

The results obtained by these papers broadly confirm the findings of more recent theoretical literature, which has attempted to embed public choice dynamics, such as lobbying practices and electoral incentives, into the classic game-theoretical framework of treaty participation (Habla and Winkler 2013; Hagen, Altamirano-Cabrera, and Weikard. 2016; Marchiori, Dietz, and Tavoni 2017).

[C]Incentives to free ride in open economies

According to classic game-theoretical literature on treaty participation, countries face a strong free-ride incentive that effectively creates a trade-off between the level of participation in environmental agreements and the abatement commitments implied by the treaty (Wangler, Altamirano-Cabrera, and Weikard 2013). As a result, environmental treaties are considered ineffective and do not induce abatement levels higher than those achievable unilaterally (Barrett 1994; Carraro and Siniscalco 1993). The general conclusion is that large coalitions can only be achieved with low abatement targets that fall short of the social optimum (Finus 2008).

Interestingly, the prevalent theoretical conclusions seem at odds with what is generally observed with treaty ratification. For example, it is common to have higher participation levels than expected from theoretical results (Marrouch and Chaudhuri,2015). Moreover, non-compliance with the agreement is rarely observed, penalties or sanctions have seldomly been applied in environmental treaties, and free-riding on commitments is generally considered less problematic than what is postulated by game theoretical models (Wagner 2001). All this may suggest some degree of discrepancy between theoretical predictions and empirical observations. However, the main problem of empirical studies dealing with participation in environmental agreements is that it is hard to appropriately control for the stringency of the agreement because the characteristics of treaties are hard to quantify and compare. Hence, it is often unclear whether these agreements involve abatement levels higher than the noncooperative equilibrium.

Some papers attempted specifically to tackle the thorny question of environmental commitments; the results are mixed. For example, Bratberg, Tjøotta, and Øines (2005) found a positive effect on abatement levels compared to the noncooperative solution, but Ringquist and Kostadinova (1985) did not. Murdoch, Sandler, and Vijverberg (2003) observe that the abatement cost plays an important part in explaining the adhesion to the

Helsinki Protocol (1985). However, the results from Beron, Murdoc, and Vijverberg (2003) point to weak free-riding incentives for the Montreal Protocol (1987) and Sauquet (2014) finds that the free-ride incentive for the Kyoto Protocol is mitigated by other types of relationships between countries, such as trade partnership and proximity. Other papers focused on the level of participation and found that the trade-off between the strictness of the agreement and the number of members is avoidable. According to Bernauer et al. (2013) and von Stein (2008), some design features of environmental agreements could promote participation and simultaneously induce tighter obligations for its members. These include small non-compliance sanctions, minimum participation rules, the definition of precise abatement targets, or inclusion of transfer mechanisms. Nevertheless, the limited amount of empirical evidence does not allow to conclusively validate or disproof theoretical predictions.

The pollution-haven hypothesis is a specific case of the incentive to free ride that has received extensive empirical coverage. This hypothesis states that, at the margin, weaker rules on pollution abatement provide a comparative advantage, which will tend to draw more pollution-intensive activities to countries with lax regulation (Copeland and Taylor 2004; Cai, Riezman, and Whalley 2013). A well-studied example of the pollution-haven effect linked to environmental agreements is the phenomenon of carbon leakage. When a group of countries—such as those in Annex I of the Kyoto Protocol—commit to reducing carbon emissions, the uncommitted countries have an incentive to increase their emissions. Kim (2016) tests for this effect within a gravity model framework. The author uses a structural break test to assess whether the Kyoto Protocol induced a change in trade flows of G20 countries, finding that a structural break probably occurred in 2003. In a similar application, Aichele and Felbermayr (2013) estimate the impact of commitment to the Kyoto Protocol on bilateral trade flows. They use matched samples with difference-in-difference estimation and find that the protocol induces a reduction of around 10 percent in the exports of Annex I countries, with energy-intensive industrial sectors being the most affected. The result is found by comparing average exports in 1999–2003 with the corresponding level in the 2004–2007. However, we suspect that a set of time-varying unobserved factors could inflate the results: the end of the second period corresponds with a slowdown in world trade, and the study period also coincides with a major shift in industrial production toward developing countries. As an illustration, the total exports of India grew from US$60 billion in 2001 to $250 billion in 2007, and Chinese exports exploded from $250 billion to $1,250 billion over the same period (World Bank 2017).

In a subsequent paper, the same authors find that the Kyoto Protocol affects trade composition. Aichele and Felbermayr (2015) employ a gravity model to calculate the embodied carbon in trade flows. They find that the embodied carbon in the imports of Annex I countries increased by 8 percent and emission intensity by 3 percent. The change in trade volume and trade composition suggest that environmental treaties may influence trade flows and thus weight over ratification decisions of some countries. Nevertheless, results for international environmental agreements are mixed, too. For instance, De Santis (2012) studies the link between three environmental agreements and trade with a gravity model. She finds that more stringent environmental policies tend to reduce exports. However, participation in environmental treaties has the opposite effect: it increases exports. De Santis (2012) observes that bilateral trade among EU-15 countries increases in a significant way after the adoption of the Montreal Protocol, UNFCCC, and Kyoto Protocol. According to Bernauer et al. (2010), countries more focused on trade are expected to be less likely to ratify environmental agreements because they are more affected by losses in comparative advantage.

On the other hand, Neumayer (2002a) argues that more intense trade leads to higher international integration and the likelihood to participate in treaties. Egger, Jeßberger, and Larch (2011) make a similar argument, positing that participation in environmental agreements increases with more liberal trade and investment policies. But, overall, trade openness does not seem to be a strong determinant of ratification. For instance, the sample of Neumayer (2002b) covers six treaties and 175 countries, and his results show that the level of imports and exports are only relevant for the agreements that impose trade restrictions: the Rotterdam Convention (1998), Montreal Protocol, and CITES (1973). The results are statistically insignificant for the other treaties in the sample (Kyoto Protocol, Cartagena Protocol, and Convention on Biological Diversity). Similarly, Wagner (2016) finds that trade relationships account for an 11 percent reduction in the time it took to ratify the Montreal Protocol. However, the effect is likely stronger for the Montreal Protocol than for other treaties because it contains an explicit trade ban on CFCs commerce with non-ratifiers.

[B]International Interaction

Foreign interactions are probably the most studied factors in the empirical ratification literature. Ratification is seen as a strategic move that depends not only on the country's characteristics and treaty but also on the behavior of foreign nations. Therefore, the empirical research focuses on understanding how economic and diplomatic ties between nations influence ratification choices.

The benefits of environmental agreements are typically non-rival and non-excludable—for example, non-ratifiers cannot be excluded from the environmental benefits of the Paris Agreement (2015). Despite the incentive to free ride, empirical evidence shows that foreign ratification, especially by big nations, increases the ratification likelihood of other nations. The empirical literature agrees that this effect is partly explained by economic and political ties between countries (Sauquet 2014). These create interdependence and mitigate the free-riding incentive postulated by noncooperative game-theoretical models.

Empirical studies usually test the effect of foreign actions on domestic ratification choices by inserting foreign ratifications as explanatory variables (i.e., spatial lags). These are then aggregated by using weighting matrices based on the value of bilateral trade, geographic proximity, diplomatic ties, GDP, or other factors. Typically, past ratifications are used as an instrument to mitigate risks associated with the endogeneity of foreign ratification. The results from this type of model show that ratification likelihood increases after foreign nations decide to participate in treaties. Bernauer et al. (2010) and Perrin and Bernauer (2010) find that this is particularly true in the case of "peer nations" in the same geographical area or income bracket. Even after controling for the regionality of agreements, Bellelli, Scarpa, and Aftab (2020) find that countries are strongly affected by the ratification decisions of foreign nations in the same geographical region. They estimate that the probability of ratification increases by as much as 80 percent if all neighbors ratify the treaty. Both Bernauer et al. (2010) and Bellelli, Scarpa, and Aftab (2020) obtain these results on samples containing more than 200 different environmental agreements. Studies on single agreements further confirm these findings and suggest that the impact of international linkage may vary according to the specific features of the treaty. For example, Sauquet (2014) reports that the likelihood of ratification for the Kyoto Protocol is affected by trade partners' behavior in green investment projects, while neighboring countries do not have a significant influence. Given the global scale of greenhouse gas emission externalities, it is plausible that proximity is less relevant in the case of the Kyoto Protocol.

Davies and Naughton (2014) build a model of pollution tax competition with transboundary pollution spillovers and test it with ratification count data. They find that the number of ratifications of other OECD countries correlates significantly with the domestic number of ratifications. In contrast, the ratification of non-OECD countries—except for regional agreements—is insignificant. The problem with this study is that the number of treaty ratifications is a misleading measure: correlation in the aggregate number of ratifications does not imply cooperation between nations. Two countries may simply be ratifying different agreements in similar numbers. Moreover, two neighboring countries will likely be exposed to a similar set of treaties; hence correlation is driven by their eligibility to ratify a similar number of agreements rather than an increased propensity in cooperation.

Schneider and Urpelainen (2013) take advantage of a natural experiment to study the influence of the United States and the European Union in the ratification of environmental agreements. The study exclusively looks at the Cartagena Protocol (2000) on biosafety regulation. Opposed by the United States, this treaty promoted the European Union's stance against genetically modified organisms, which the United States viewed as damaging its agricultural export interest. According to Schneider and Urpelainen (2013), the two powers competed to influence the treaty's ratification by third nations. They find that the more a country depends economically or diplomatically on one of the two powers, the more it aligns its international policy with such power.

The empirical literature also finds that countries are more likely to ratify environmental agreements when economically and diplomatically integrated with the rest of the world. Frank (1999), Bernauer et al. (2010), and Yamagata, Yang, and Galaskiewicz (2013) argue that the more a country is linked to the international community through trade and diplomatic activity, the more likely it is to join environmental agreements. In essence, ratification would be driven by a country's degree of global integration. Integration is often proxied by the number of memberships to international organizations, international NGOs, and international intergovernmental associations. Bernauer et al. (2010) explain that membership in international organizations indicates an openness to cooperation and should increase available information and reduce costs for forming multilateral agreements.

Moreover, if a country linked to the international community does not ratify a treaty, it suffers a loss in reputation and expects other nations to refuse cooperation in other areas (Finus 2008; Bernauer et al. 2010). Thus, according to Frank (1999), global integration is the main determinant of ratification. However, this result does not take into account possible sources of endogeneity in the variables. Moreover, another issue with global integration is that it correlates with the number of agreements the country has access to. More integrated nations tend to negotiate more agreements; hence they are more likely to ratify agreements. Unfortunately, existing studies have not properly tackled this source of endogeneity.

Another contribution to this topic comes from Wagner (2016). In the first part of the paper, Wagner (2016) builds a game-theoretical model of delay in ratification, which depends on complementarity or substitutability in countries' ratifications. The model is then tested empirically with data on the Montreal Protocol ratification, using a survival model with spatial lags. The result of Wagner (2016) indicates that ratifications of the Montreal Protocol exhibit strong complementarity. On average, the complementarity effect accelerated ratification time by 12 percent (208 days). Three factors mainly explained complementarity: i) economic dependency and trade, ii) issue linkage and reputation costs, and iii) fairness. Among the three factors, economic dependency seems to have the strongest acceleration effect on ratification timings.

Similarly, Yamagata, Yang, and Galaskiewicz (2013, 2017) use a spatial lag model to explore the correlation in countries' ratification choices. They explore different weighting matrices for the spatial lag, such as the presence of shared language, religion, or common membership in international organizations. While the 2013 study includes only two climate change agreements the 2017 study expands the analysis to eight treaties. The latter study runs two separate regressions, one for 1981–1990 and the other for 1991–2008. Treaty dummies are included to control for unobserved treaty characteristics. Both papers conclude that global integration and ratification by large nations play a critical role in domestic ratification decisions.

Finally, some researchers emphasize that the act of ratification expresses the feasibility of the environmental project and is used as a signaling tool to foreign and domestic actors (Perrin and Bernauer 2010; Hugh-Jones, Milewicz, and Ward 2018). Their arguments are based on the policy diffusion literature, which stipulates that the adoption of a policy conveys information on reputation costs, environmental commitment, and implementation costs. A small number of papers upholds this thesis. For example, Schulze and Tosun (2013) hold that some countries are willing to ratify agreements and align their environmental standards with the European Union because they anticipate potential returns in the form of aid, assistance, access to the EU market, and even EU membership. Their sample includes twenty-five non-EU members and twenty-one environmental agreements negotiated under the UN Economic Commission for Europe (UNECE). More distant UNECE members (e.g., Israel or Tajikistan) exhibit a lower propensity to ratify environmental agreements than proximate members that aspire to join the EU and are economically dependent on the EU. A similar analysis is conducted by Milewicz and Elsig

(2014) with a survival approach on a sample of seventy-six multilateral agreements—although not exclusively environmental agreements. They claim that new democracies in Europe ratify treaties to please the European Union, signal political autonomy, and gain international recognition. These findings are echoed by Cortez and Gutmann (2017)—again, with a sample that includes more than just environmental agreements—who find that recent democracies are more likely to ratify all types of treaties. The higher ratification rate strongly substantiates the quest for international recognition by young democracies and the signaling role of treaty ratifications.

[A]Conclusion and Policy Recommendations

This literature review presents the main factors associated with the ratification of environmental agreements, which can be broadly grouped into three categories: i) domestic factors, ii) treaty characteristics, and iii) international interactions. Domestic factors, such as the political system, the income level, the interests of dominant pressure groups, or the country's export structure, strongly shape the set of incentives and costs associated with ratification. However, the characteristics of the treaty are arguably even more important; agreements that promote stricter environmental regulations are relatively more onerous for the parties and, as such, are joined more reluctantly. Nonetheless, empirical findings show that some types of clauses can increase participation, and the strong interdependence between nations mitigates the free-riding incentive. Not only will ratifiers try to influence other nations to join, but economic and diplomatic partners might use the ratification of environmental agreements to reinforce partnerships and strengthen their negotiation position on other cooperation issues. Under the right circumstances, a non-ratification bears a reputational cost.

Several useful policy insights can be drawn from this body of research. First, treaty provisions can foster participation without compromising effectiveness. Just as theoretically predicted, minimum participation rules, flexibility mechanisms, financial assistance, and technological transfers to developing nations can help improve participation. Transfers are decisive factors for the participation of developing nations (Mohrenberg, Koubi, and Bernauer 2016; Spilker and Koubi 2016).

Second contrary to expectations, monitoring mechanisms and small sanctions serve as a cheating deterrent and are not associated with reduced participation (Bernauer et al. 2013). In this regard, a treaty structured as a climate club (Nordhaus 2015) could be a viable solution. For instance, the very successful Montreal Protocol managed to attract wide participation and achieve effective environment improvements by imposing sanctions for non-compliance and setting trade restrictions between members and non-members on products related to ozone-depleting substances.

Another emerging suggestion is to frame global treaties as interlocked regional agreements. As the number of negotiating parties increases, finding common ground can become increasingly hard. Therefore, participation could be improved by splitting negotiation into regional agreements (Bellelli et al., 2020).

Empirical modeling also stresses that the first year of an agreement is crucial for its success. As time passes, the agreement "cools down" and reduces its chances of attracting ratifications. Securing early ratification of big players can be a decisive factor in triggering a domino effect in participation (Bernauer et al. 2010; Wagner 2016; Yamagata, Yang, and Galaskiewicz 2017). In this regard, empirical findings are particularly encouraging. The strong linkage between nations implies that a handful of countries could make the difference.

Finally, participation in environmental agreements can also be fostered with environmental lobbying and campaigning. Agreements with intense media coverage systematically attract higher ratification rates, and environmental lobbying actions have a significant effect in democracies (Fredriksson et al. 2007; Böhmelt, Bernauer, and Koubi 2015).

The scope of this paper has been to summarize the progress achieved in the empirical research on treaty ratification and take stock of the main findings. As much as possible, we also attempt to compare these findings with the predictions of the contiguous game-theoretical literature on treaty participation. By so doing, we hope to bridge two bodies of research that have mostly evolved in parallel. Further research in this area—particularly regarding treaty design—could expand our limited understanding of the factors that underpin successful environmental cooperation. We hope that this collection of empirical results will help build more realistic models of environmental cooperation and improve our capacity to address transboundary environmental issues.

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Supplementary material

A review of the empirical strategies for the study of environmental agreements

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The act of ratification refers to a specific agreement, originates by a distinct country and occurs at a fixed point in time. In essence, it is qualified by three dimensions: the ratifying country, the ratified treaty, and the year of ratification. According to their methodology, the empirical research emphasised different combinations of these dimensions, looking from different angles at the same phenomenon. Over time the methodological approaches followed a process of refinement, gradually attempting to include all three dimensions and leading to more general conclusions on ratification. We broadly distinguish between three empirical approaches to empirical ratification analysis:

i) ratification counts, *ii*) survival analysis for single agreements, and *iii*) pooled survival analysis. In this appendix we describe each of these approaches, their applications, characteristics and limitations. Moreover, as a reference to the reader, we provide at the end of each section a table summarising the sample and models of surveyed studies adopting that approach (Tables 1, 2 and 4).

1 Ratification counts

The first step in the analysis of ratification is to find an appropriate way of "measuring" the ratification behaviour of countries. This is usually done by looking at the ratification status of one or more treaties at a specific moment in time and counting the number of treaties ratified by every country. If only a single agreement is involved, the maximum count is 1 and the variable is binary. If more than one agreement is studied, the variable represents the total number of treaties in which the country decided to participate. We call this type of variable a *ratification count*, to distinguish it from the survival data employed in later studies (e.g. Fredriksson et al. 2007, Bernauer et al. 2010). Count studies focus primarily on the difference in the number of ratifications among countries, while the evolution in time is generally ignored. Almost all of the studies measuring ratification in a

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"count" fashion adopt a cross-sectional approach. Egger et al. (2011 and 2013) and Davies and Naughton (2014) are the only panel studies using count data (see Table 1).

Depending on whether the study covers a single treaty or multiple treaties, the researcher deals with two different types of data. Hence, different empirical strategies are used. When the study is limited to a single agreement the ratification data is represented by a binary variable: this type of analysis is approached with binary regression. When multiple agreements are studied, the dependent variable is the total number of ratifications: this data is approached either with a linear regression or with regression techniques for count data.

2 Single agreements: the binary outcome

As mentioned earlier, the simplest case of ratification counts is when only a single agreement is studied (e.g. Beron et al. 2003, Murdoch et al. 2003) or when agreements are modelled individually (e.g. Congleton 1992, Neumayer 2002a). In these cases the dependent variable is binary because the maximum count is 1.

Binary ratification choices are tackled with a binomial regression to study how differences among countries affect the odds of ratification. This approach has been implemented in numerous studies. Congleton (1992), Almer and Winkler (2010) and Neumayer (2002b) use it to model the signature of environmental agreements. Murdoch et al. (2003) and Beron et al. (2003) study the ratification of two different protocols by 25 and 89 countries, respectively. Additional work is conducted by Almer and Winkler (2010) and Fredriksson and Ujhelyi (2006), both investigating the ratification of the Kyoto Protocol by circa 170 countries.

These papers study exclusively one agreement, raising the question of how the results can be generalised beyond the single case. They fulfil a descriptive purpose and offer little insight into the general process of ratification. This is probably the main weakness of this approach. Frank (1999) and Neumayer (2002a and 2002b) attempt to expand the range of this type of studies by modelling several agreements in parallel. However, the results are still based on individual models for each treaty and the dimension of the sample is relatively small. In principle, the approach could be extended to several agreements by using ratification dummies for treaty-country dyads; however, this strategy has never been implemented.

3 Multiple agreements: counting ratifications

Whenever the number of ratifications are counted for two or more agreements, we are effectively dealing with count data. This type of data has been fitted with count models and — more commonly, but less appropriate given the positive and discrete nature of the count variable — with linear models. Ratification counts are an easy way to expand the base of treaties included in the analysis because with this approach less information is required compared to approaches based on survival analyses. Recchia (2002) covers 15 environmental treaties, Roberts et al. (2004) 22 and Seelarbokus (2014) reaches 110 agreements. This is considerably more than any other cross-sectional study using binary variables.

Nonetheless, the simple count of ratifications gives rise to a likely misleading variable if the objective is to define a country's appetite for international cooperation. The implicit assumption is that more ratified treaties lead to stronger environmental commitments. This assumption is debatable because environmental agreements are profoundly different among them: simply adding treaties up without adequate weighing is like summing 'grapes and melons'. The number of agreements that are ratified is unlikely to be proportional to either the environmental commitment of the country or representative of its engagement in the international arena of environmental cooperation. To a large extent, the number of ratified treaties is just a reflection of the number of treaties the country can access. To this end, to evaluate a country's opportunity set, it is critical to know the number of neighbours and environmental issues in which a country could be involved. As an illustration, Kiribati is an insular state in the pacific, despite its interest in preserving the environment, it undoubtedly ratifies fewer agreements than Indonesia, a big state with several neighbours and a rich natural asset. This is due to the massively different opportunity set between the two countries, more than to the country's appetite for international cooperation. Regrettably, neither Seelarbokus (2014) nor Roberts et al. (2004) controlled for these important factors.

We suggest that ratification rate would be a better measure than the mere count of the number of ratifications. Of course, this entails identifying the potential ratifiers of each treaty, a practice implemented for the first time by Bellelli et al. (2020). There has also been some attempt to use score systems instead of simple ratification counts. They usually work by assigning points for signatures and ratifications (Recchia, 2002) or by weighting the number of ratifications by the total number of ratifiers (Roberts, 1996). It unclear what these indices could teach about the ratification of environmental agreements. In general, score systems tend to obfuscate the results, making the relationship between variables opaque.

A less obvious consequence of ratification counts is that the connection between the ratifying country and the ratified treaty can be maintained only if each agreement is studied individually. That is to say, if we sum all the ratifications of a country, we would not be able to tell which types of treaty it has ratified, except in the trivial cases in which it has ratified none or all of them. This feature is a severe limitation to using count variables because it does not allow researchers to study how the design of the treaty affects ratification. The characteristics of a treaty can be accounted for only by studying a cross-section of treaties and counting the number of ratifications it has received, just as in Bernauer et al. (2013b). However, this implies that it would now be impossible to know what country ratified, and to consequentially investigate the role of a country's characteristics in the process. In essence, with such dependent variables, there is a trade-off between studying the characteristics of the country or the treaty.

4 Cross-sectional approach

Virtually all count studies adopt a cross-sectional approach; the only ones employing panel data are Egger et al. (2011 and 2013) and Davies and Naughton (2014).

The first problem encountered by the researcher applying cross-sectional approaches is to choose the right cut-off date. Since data is right-censored by construction, ratifications that took place after the cut-off date are ignored. For more recent treaties this could lead to misleading results because the selection of the observation point can arbitrarily influence the results. The choice of the cut-off date is a common problem in studies using ratification counts. For instance, Beron et al. (2003) allow only three years for the ratification of the Montreal Protocol (1987), while in Murdoch et al. (2003) the observations on the Helsinki Protocol (1985) are taken after five years: in both cases, most of the ratifications were not yet deposited by the time the analysis took place. Congleton (1992), Neumayer (2002a) and Neumayer (2002b) study recent environmental agreements but mitigate the problem by focusing on the act of signature — which typically takes place during the first year of the treaty — instead of the act of ratification. The problem is particularly serious for studies with large samples of treaties because different treaties are exposed to ratification processes for different lengths of time. All the studies mentioned in this section fail to address this issue, except for Bernauer et al. (2013b), who account for the exposition factor by using a negative binomial model.

An additional problem of cross-sectional studies is that they ignore the temporal dynamics of ratification. Many domestic policy and institutional factors are likely to influence the timing rather than the occurrence of ratification. For example, Spilker and Koubi (2016) analyse how different domestic voting requirements for the ratification of international treaties influence the likelihood of ratification. It is reasonable to expect that complex or stricter requirements would make the adoption of a treaty not just more laborious, but also slower. The empirical results support this view, countries that require a supermajority in parliament for the approval of treaties are slower and less likely to ratify environmental agreements. Moreover, if time is ignored, it is also impossible to discern the order in which different countries decide to join a treaty, which could provides useful evidence of the diplomatic interactions at play (Almer and Winkler, 2010).

5 Panel approach

The obvious solution to the omission of time effects is to use stacked cross-sections to create a panel dataset, this approach has been attempted by Davies and Naughton (2014) and Egger et al. (2011 and 2013). Davies and Naughton (2014) study participation in 110 environmental agreements by 139 countries over 20 years (1980–1999). The dependent variable is a count of ratifications. The study has a very robust methodological approach; the main weakness of the paper being the use of count data. Davies and Naughton (2014) build a spatial model and experiment with different estimators (notably 2SLS and GMM). They use an instrumental variable approach to address endogeneity in one of the variables

(Foreign Direct Investment, or FDI) and include country and year fixed effects to account for fixed unobserved factors.

Unfortunately, the use of count data does not serve well the aim of Davies and Naughton (2014). Their objective is to assess the influence of FDI on environmental policies and determine whether ratification is sensitive to the participation decision of neighbouring countries. The problem with choosing the count of ratifications as dependent variable is that it obfuscates interactions between countries. Does the fact that foreign nations ratified a higher number of agreements mean that they had an impact on the domestic ratification choices? How do we know they ratified the same agreement? Could it not reflect the fact that a larger number of agreements have been agreed and are open to ratification? The research question cannot be properly answered because count data does not allow to compare ratification choices within the same agreements. Indeed, count data lumps together the ratifications of different treaties, thus losing information on which specific treaties was ratified by every given nation.

Similarly to the previous study, the dependent variable in Egger et al. (2011 and 2013) is the number of agreements in which a country participates at any given point in time. The definition of "participation" is not clear in the 2011's paper: it appears that a country is considered to be a participant if it either signs or ratifies an agreement, regardless of which. However, in Egger et al. (2013) reference is made to the act of ratification. Their data covers the ratification status of around 350 treaties for 105 countries — of which only 17 Less Developed Countries (LDCs), suggesting that there could be sampling bias. The same control variables and methodological approach are used in both papers. In both Egger et al. (2011) and Egger et al. (2013) a dynamic feedback model for count data with lagged dependent variable is used to model the number of ratifications. The main difference is that in Egger et al. (2013) a separate model is estimated for different clusters of environmental treaties (atmosphere, land, sea, biodiversity protection and hazardous waste).

The main downside of a panel approach with count data is that it does not allow the analyst to escape the trade-off between country and treaty characteristics. If the dependent variable is the number of ratified treaties by the country at a given point in time, then it is not possible to know what treaty the country has ratified. Consequently, the characteristics of the treaties cannot be used to explain its ratification. In the same way, if the focus is on the number of ratifications received by the treaty at time *t*, then it is not possible to discern which country ratified and take into account the characteristics of the country to explain the ratification choices.

Table 1: Studies modelling ratification as a count or binary variable

Paper	Sample	Dependent variable	Model

Congleton (1992)	118 countries, Vienna Convention (1985) and Montreal Protocol (1987).	Signature by 1989, binary variable.	Logistic regression.
Roberts (1996)	145 countries, 9 environmental agreements.	Weighted number of ratifications between 1963–1987.	Linear regression.
Frank (1999)	Unspecified number of treaties, between 41 and 114 countries depending on time window.	Total number of treaties ratified by a country over 4 time windows.	4 latent variable regressions.
Neumayer (2002a)	6 agreements, maximum of 175 countries.	*i*) Survival data for ratification of 3 agreements. *ii*) Binary variable for the signature of 3 other agreements by 2000.	*i*) Cox PH models for 3 treaties with high ratification rate. *ii*) Probit models for the signature of 3 recent agreements for which ratification process is at its beginning.
Neumayer (2002b)	4 agreements with non-universal ratification, maximum of 175 countries.	Binary variable for the signature (ratification for the Montreal Protocol, 1987) by 2000.	*i*) Probit regressions for single agreements. *ii*) Ordered probit for joint regression (from 0 to 4).
Recchia (2002)	15 global environmental agreements, 19 democracies.	Country score calculated by assigning 3 points for each ratified agreements and 1 point for signature.	Linear regression.
Beron et al. (2003)	Montreal Protocol (1987), 89 countries.	Binary variable for ratification by 1990.	Probit with spatial lag. Weighting matrix based on bilateral trade.
Murdoch et al. (2003)	Helsinki Protocol (1985), 25 European countries.	Binary variable for ratification by 1990.	Probit model.
Roberts et al. (2004)	22 agreements, 192 countries.	Index based on the number of ratifications between 1947-1999.	Linear regression.
Almer and Winkler (2010)	Kyoto Protocol (1997), 165 countries.	*i*) Binary variable for the signature and *ii*) ordered variable for the ratification of the protocol.	A latent variable approach is used for the binary variable (signature yes/no) and an ordered response model for ratification (ratified in period 1, 2 or 3).
Egger et al. (2011)	353 agreements between 1960 and 2006, 105 countries.	Number of agreements in which a country is participating.	Dynamic panel linear feedback model for count data, estimated with GMM.

Egger et al. (2013)	110 countries, more than 212 agreements signed between 1960 and 2006	Number of participation in agreements by country.	Dynamic panel linear feedback model for count data, estimated with GMM. A model is estimated for every cluster of environmental treaties (atmosphere, land, sea, biodiversity protection, hazardous waste).
Bernauer et al. (2013b)	200 agreements.	Total number of ratifications received by each agreement by 2006.	Negative binomial regression.
Davies and Naughton (2014)	110 environmental agreements, 139 countries over 19801999.	Number of agreements ratified.	Panel count spatial model with weights based on bilateral distance. Country and year fixed effects. Estimated with GMM-IV and 2SLS.
Seelarbokus (2014)	110 environmental agreements, 108 countries.	Number of treaties ratified or signed by each country.	Linear regression.

6 Survival analysis

So far, we discussed the studies that "measure" ratification behaviour by counting ratification acts by countries. While this approach is the most common in earlier studies, later studies shifted towards the use of survival analysis. Survival analysis derives its name from the epidemiological background of the technique; it is used to study the probability of occurrence of an event at a specific point in time. Following this approach, the ratification of environmental agreements is characterised by two dimensions. The first is whether or not ratification takes place — the *occurrence*. The second is the *timing* to ratification. Hence, compared to ratification counts, survival data incorporates additional information regarding the variation of timing across countries. In this section, we only review those studies that either focus on single treaties or model treaties individually (see Table 2). This methodology can be extended to a plurality of agreements as described in the next section.

The first application of survival models to the ratification of international agreements was by Fredriksson and Gaston (2000), where the authors argue that country's environmental commitment drives the speed of ratification. This relationship, however, also dependent on frictions encountered during the internal procedures of ratification, which vary across different institutional designs. Unfortunately, Fredriksson and Gaston (2000) failed to account for such aspects in the timing of ratification. In subsequent research, it was realised that time to ratification is a better dependent variable than the simple occurrence of ratification, because many factors result in changes in timing rather than occurrence (von Stein 2008, Fredriksson and Ujhelyi 2006). This notion is particularly important in works focusing on the role of political and economic variables. In fact, at the margin, a slightly more complex bureaucratic system, or a small increment in the pressure of environmental groups, are more likely to affect the timing rather than completely reversing the outcome of ratification.

7 The information value of timing of ratification

Compared to ratification counts, survival analysis allows taking advantage of the information carried by the timing of ratification. This added dimension allows researchers to expand the scope of the empirical analysis to address new types of questions.

Focus on timing of ratification allows researchers to gather information by observing the behaviour of countries over a specific observation period. Such period starts when the treaty is opened to the debate leading to ratification. From that moment, the country is considered *at risk* of ratification. Ratification by different nations is then tracked throughout time until the cut-off (censoring) year. Ratifications that take place after the censoring year are ignored. Nevertheless, survival analysis is designed to cope with right-censoring. Estimation results are unbiased as long as the assumption of noninformative censoring is satisfied. That is to say, whenever the ratification process and the observation cut-off date are independent.

The advantage of the survival approach is that it can measure ratification over an additional dimension: that of time. Neumayer (2002b) uses this approach to his advantage as he observes that a cross-sectional ratification count study is unable to detect variability within almost-universally ratified treaties. He applies the technique to the Montreal Protocol (1987), CITES (1973) and the Biodiversity Convention (1992), which, by the time the analysis was conducted, had already been ratified by a very large number of nations. In general, survival analysis is a superior approach for universally ratified treaties because it takes advantage of the heterogeneity in the time dimension, while a cross-sectional count study fails to capture any differences in the ratifications when almost all countries have ratified. Survival analysis is also capable of dealing with rightcensoring and thus it is better suited to the analysis of recent agreements with ongoing ratifications.

Most of single-treaty survival studies focused the Kyoto Protocol (1997) and the UNFCCC (1992). Climate change agreements received a meticulous coverage not only because of their high media exposure, but also because of the rich anecdotal literature surrounding the manners negotiation was conducted and the debate behind participation in climate treaties. The COP [4] meetings are scrutinised by political scientist (Roger and Belliethathan 2016, Dimitrov 2016) and negotiation dynamics (Brandt and Svendsen 2004, Babiker et al. 2002), rules (Nasiritousi and Linner, 2016) and balances (Afionis 2011, Kasa et al. 2007) are carefully studied to explain countries' order of ratification (e.g.Andresen and Agrawala 2002, Lund 2013, Chin-Yee 2016). Survival analysis suits this

[4] Conference of the Parties (COP) is the annual meeting of the members of the UNFCCC (1992), Kyoto Protocol (1997) and the Paris Agreement (2015). National delegations gather to "keep under regular review the implementation of the Convention and any related legal instrument" (Art.7, UNFCCC 1992). COP meetings are attended by thousands of participants from NGOs, scientific organisations, universities, government bodies, industry representatives, media, and civil society in general.

branch of literature because it allows to test the ratification sequence in ways that are impossible with count data.

Neumayer (2002b), Wagner (2016) and Schneider and Urpelainen (2013) are the only papers that do not focus on climate agreements. The latter is an interesting study of the Cartagena Proctocol (2000), an agreement regulating the use of Living Modified Organisms (LMOs). The protocol puts forward the "precautionary principle" endorsed by the EU, which was thought to hinder the agricultural exports of United States by setting unfavourable international standards on LMOs. The United States strongly opposed the agreement and advocated the "sound science principle". Hence, the Cartagena Protocol is seen by the author as a natural experiment to test how political and diplomatic linkage with the Unites States and European Union affect the ratification behaviour of third states. Again, the choice of survival modelling is linked to the need of studying the sequence of ratification by different countries, which is easily performed with survival analysis.

8 Modelling choices

Among survival studies, the first difference in the methodological approach refers to the treatment of time. In many studies, time is treated as continuous even though models are based on yearly or monthly observations of ratification. Furthermore, the explanatory variables are always measured yearly. Hence, a common assumption is to take their values as constant throughout the year if the model is specified for monthly (von Stein 2008 and Schneider and Urpelainen 2013) or daily ratification (Fredriksson and Gaston 2000 and Fredriksson et al. 2007). The distinction between continuous and discrete observations is often a nuanced one. The ratification of an international agreement is *per se* a continuous process, however it is registered on time intervals of various length (years, months, weeks or days). Technically, it is a grouped survival data problem, because an underlying continuous process is observed discretely, hence the observations are grouped over an interval. So, despite the natural discreteness of the underlying data, depending on the granularity of the analysis, the variable could be assumed as continuous. Shorter observation intervals, such as days or weeks, over a long enough time period, could easily be considered a continuous representation of the ratification process. For annual observations the assumption is harder to justify (Neumayer, 2002a).

Yamagata et al. (2013) and Sauquet (2014) are the only papers opting for a discrete approach.

In terms of model specification, the Cox proportional hazard model is the model of choice in the majority of the cases (Fredriksson and Gaston 2000, Neumayer 2002a, Fredriksson and Ujhelyi 2006, Fredriksson et al. 2007, von Stein 2008 and Schneider and Urpelainen 2013). Cox PH is a popular semi-parametric survival model that does not assume any particular distribution for the survival times. The shape of the baseline hazard remains unspecified, unlike in the Weibull and the Gompertz models used by Sauquet (2014). In proportional hazard models, the explanatory variables affect the hazard rate of ratification in a multiplicative fashion. Furthermore, the hazard ratio is assumed constant over time, implying that the relationship between the explanatory variable and the hazard ratio never changes. Proportional hazard models are different from accelerated failure time models which describe the speeding up process of an event. Wagner (2016) is the only ratification study that uses an accelerated failure time (AFT) model. In AFT models, the dependent variable is the ratification time instead of the hazard of ratification (probability of ratification at time *t* given no previous ratification). Except for Wagner (2016), all the models presented in this section are proportional hazard models and assume a baseline hazard shared among all the units of the analysis. It is a simplifying assumption that could clash with the structural diversity in ratification behaviours of nations. The samples contain diverse groups of nations but, except for Fredriksson and Ujhelyi (2006) and Fredriksson et al. (2007) that stratify their models on annex I and non-annex I countries, there has been no attempt to address unobserved heterogeneity at the country level.

Table 2: Survival analysis for single treaties

Paper	Sample	Dependent variable	Model
Fredriksson and Gaston (2000)	UNFCCC (1992), 184 countries until 1997.	Ratification survival time, daily observations.	Cox PH (also modelled as cross-sectional logistic regression).
Fredriksson et al. (2007)	Kyoto Protocol (1997), 170 countries until 2002.	Ratification survival time, daily observations.	Cox PH model stratified on annex I countries (also with a Weibull model and cross-sectional logistic regression).
von Stein (2008)	Kyoto Protocol (1997) and UNFCCC (1992), maximum of 140 countries until 2003.	Ratification survival time, monthly observations.	Separate models for the two treaties. Cox PH and Weibull specification.
Schneider and Urpelainen (2013)	Cartagena Proctocol (2000), 182 countries until 2006.	Ratification survival time, monthly observations.	Cox model allowing for non-proportional hazard. (also crosssectional logit model).

Yamagata et al. (2013)	Kyoto Protocol (1997) and UNFCCC (1992), maximum of 166 countries until 2008.	Ratification survival time, annual observations.	Logistic regression for discrete survival data with spatial lag (multiple weighting matrices used).
Sauquet (2014)	Kyoto Protocol (1997), 164 countries until 2009.	Ratification survival time, annual observations.	Gompertz survival model for grouped observations with spatial lag (weights based on trade, proximity and CDM projects).
Wagner (2016)	Montreal Protocol, Preferential Trade Agreements and Bilateral Investment treaties. 140 countries for the Montreal Protocol, until 2015.	Ratification survival time, daily observations.	Accelerated failure time model with spatial lag estimated with method of simulated moments (weights based on trade, IO membership and CFC emissions).

9 Pooled survival analysis

The survival approach can be extended to simultaneously deal with several treaties by pooling together the survival information of a group of treaties. Strictly speaking, the techniques used in this case are the same as in the previous section; the only difference is that, instead of dealing with countries, the unit of analysis is the country-treaty dyad. Bernauer et al. (2010) is the first study that pools together various treaties in a single survival model. Since then, this approach has been applied several times (see Table 4). Most of the recent studies choose to adopt this approach over the ones described in previous sections. This approach yields coefficient estimates that are general; they do not fit the specific treaty, instead they are intended to represent the process of ratification as a whole. From a methodological viewpoint, pooled survival models are more complex because they need to account also for the heterogeneity at the treaty level.

10 Ratification data sets

The first advantage of pooling different treaties together is that the number of observations is remarkably larger. The total size of the sample can be extended in any of the three dimensions of the analysis, by including more treaties, covering more countries or by lengthening the observation time. For each treaty-country dyad the beginning of the observation period corresponds to the signature year of the agreement and ends either with ratification by the country or on the cut-off year of the observation period. Most of the pooled survival studies use the ratification data collected by Bernauer et al. (2010)[5]. Their data set is notably larger than all previously used: It covers 180 countries and over 250 treaties. While earlier studies focused mainly on big environmental agreements, the data collected by Bernauer et al. (2010) allowed to diversify and expand the analysis to a profusion of smaller and lesser known agreements, considerably enriching the debate on ratification. In comparison, other data sets are relatively narrow in terms of countries and treaties. For example, Schulze (2014) only focuses on OECD countries and Leinaweaver (2012) cover 198 countries and only 55 agreements. Table 3 reports the sizes of a selection of large datasets used to study the ratification of environmental agreements.

Table 3: Ratification data sets

Data set	Treaties	Countries	Years	Regional treaties
Bellelli et al. (2020)	263	198	1950–2017	Yes
Bernauer et al. (2010)	255	180	1950–2000	No
Leinaweaver (2012)	55	193	1980–2010	Yes
Schulze and Tosun (2013)	21	25	1979–2010	Yes, all
Schulze (2014)	64	21	1971–2003	No
Cazals and Sauquet (2015)	41	99	1976–1999	No

The downside of pooling together many treaties is that it introduces the risk of sampling bias. In order to obtain generally valid ratification estimates, the sample needs not only to guarantee unbiasedness with respect to the mechanism of exclusion of countries from the sample, but also to be representative of the whole population of environmental treaties. Regrettably, in the context of previous studies, and except for Bellelli et al. (2020), the risks associated with sampling bias have not been thoroughly investigated and discussed. By construction, survival data on ratification has no discontinuity and is never left-censored, therefore missing observations occur among the explanatory variables rather than in the dependent. In larger studies we find no evaluation of the potential distortions deriving from the exclusion of countries with missing observations in the explanatory variables; and in the same way, the sensitivity of results to inclusion rules in the treaty sample has rarely been assessed. For example, regional

[5] Their data set is used in the following works: Bernauer et al. (2010), Bernauer et al. (2013b), Bernauer et al. (2013a), Bo¨hmelt et al. (2015), Mohrenberg et al. (2016), Spilker and Koubi (2016) and Hugh-Jones et al. (2018)

environmental agreements have been either neglected or incorrectly handled in virtually all empirical studies. We now turn our attention to this category of treaties.

11 Mis-identification of potential ratifiers in regional treaties

Most of the ratification studies focus on *global* agreements (Bernauer et al. 2013a, Cazals and Sauquet 2015, Yamagata et al. 2017). These are those open to all nations and to which every nation is *de facto* a potential ratifier. Unfortunately, except for studies focusing on specific treaties or restricted to a group of countries (Perrin and Bernauer 2010, Schulze and Tosun 2013, Schulze 2014, Yamagata et al. 2017), many less-thanglobal agreements have inadvertently been mixed with those with with global coverage. we call *regional* all the treaties that do not have strictly global coverage, without distinction for their scale or scope. The real concern is not so much that regional agreements have been included in the analysis, rather that they were incorrectly handled within the analysis. Note that most of the activities of environmental diplomacy take place at the regional level, therefore global agreement only represent a facet of international environmental cooperation (Leinaweaver, 2012). For regional agreements the situation is quite different: they have, by definition, a different set of potential ratifiers from those for global treaties. Unfortunately, in most of the literature it has always been implicitly assumed that all countries that did not ratify an agreement were either eligible or potentially capable of ratifying. As argued in Bellelli et al. (2020), this assumption holds for global treaties, but it becomes much less defensible when applied to regional agreements. In econometric terms it equates to incorrectly identifying the countries in the risk set. More specifically, it has been assumed that all existing countries are at risk of ratifying, while only a subset of them truly are. The resulting survival estimates are inevitably and systematically biased upward.

The data set assembled by Bernauer et al. (2010), and used in most of the studies, seems to be affected by this issue of mis-identification of potential ratifiers in regional agreements. There are good reasons to believe that a large fraction of their sample is indeed composed by regional agreements. Bernauer et al. (2010) are aware that some of the agreements could be *de facto* open only to a restricted number of countries. Hence, in their appendix they estimate a model exclusively on provenly global agreements, which results in their sample size being halved. Even in Leinaweaver (2012), where global and regional agreements are explicitly modelled jointly, the risk set appears to be incorrectly specified. Leinaweaver (2012) attempted to control for the regionality of a treaty by including dummies for the geographic regions of the ratifiers. However, this method is insufficient to correct the potential bias resulting from the erroneous specification of the risk set. The mis-identification of potential ratifiers was first exposed by Bellelli et al. (2020), who proposed an approach to correct the bias which consists in identifying the potential ratifiers for every environmental agreement in the sample.

Fortunately, the mis-identification bias we have just described does not affect all studies, as some studies with limited samples of either treaties or countries remain immune. For instance, Perrin and Bernauer (2010) and Schulze and Tosun (2013) exclusively focus on agreements negotiated under the UNECE[6]. Their analyses are confined to UNECE members because they perceive that non-UNECE nations may not ratify these treaties. With similar implications, Schulze (2014) exclusively focuses on the ratification by OECD nations, even if the agreements in their samples are open to other countries. Finally, Yamagata et al. (2017) is unaffected by the misidentification bias because their study is limited to eight agreements, all of which global.

12 Modelling choices and unobserved heterogeneity

In terms of choice of specification in the models, the studies differ mostly in two respects *i*) how time is defined and *ii*) in the manner unobserved heterogeneity is handled at the treaty and country levels. Observations are always taken annually, except in Cazals and Sauquet (2015) who track ratification daily and assume the explanatory variables are constant over the year. A discrete treatment of time is prevalent. This approach involves expanding the survival data into a binary format in order to be explained by a binary regression model. Then, the baseline hazard is generally parameterised with either splines or cubic polynomials to allow for non-linearity. The estimates approximate those obtained with continuous survival models. The preferred modelling choice for continuous specifications of time is Cox PH models (Bernauer et al. 2013a, Schulze 2014, Cazals and Sauquet 2015 and Hugh-Jones et al. 2018).

With regards to unobserved heterogeneity, it can take place essentially at two levels: the country and the treaty level. We note, with some concern, that most of the studies with large samples (Bernauer et al. 2010, Perrin and Bernauer 2010, B¨ohmelt et al. 2015, Mohrenberg et al. 2016, Spilker and Koubi 2016) account for neither of these. Such shortcoming may justify some doubts on the consistency of the estimates. But, there are exceptions. For example, Cazals and Sauquet (2015) account for unobserved heterogeneity at the country level by including a "shared frailty" term in a continuous survival model. In survival analysis shared frailty is the equivalent of a country random effect[7]. Yamagata et al. (2017) control for treaty heterogeneity by including treaty dummies. Schulze (2014) and Hugh-Jones et al. (2018) account for heterogeneity across treaties by stratifying their models on the environmental subjects of the treaties (HughJones et al., 2018, see, for example,) or on each individual treaty (Schulze, 2014, as in). The problem with stratification is that it roughly corresponds to modelling each treaty (or group of treaties) separately. This type of solution rules out heterogeneity, but limits the ability to produce general inferences and it is harder to apply in large data sets. Finally, Leinaweaver (2012), Schulze and Tosun (2013) and Bellelli et al. (2020) are the only

[6] United Nations Economic Commission for Europe

[7] Fixed effects are not usable with survival data because they perfectly predict non-occurrence. In other words, it would exclude all the units for which the event does not occur because their observations do not vary. The resulting survival estimates would be based solely on the units that experienced ratification.

studies to date dealing with heterogeneity that can arise at both the country and the treaty level. These are modelled with random effects in a multilevel structure.

Table 4: Pooled survival analysis

Paper	Sample	Dependent variable	Model
Bernauer et al. (2010)	255 environmental agreements between 1950 and 2000, 180 countries.	Survival data on ratification recorded annually.	Binary regression for grouped survival data (also a cross-sectional logistic regression).
Perrin and Bernauer (2010)	9 Long-Range Transboundary Air Pollution (LRTAP) agreements, 47 Eurasian countries that ratified the 1979 convention. Between 1979 an 2007.	Survival data on ratification recorded annually.	Logistic regression for grouped survival data (also conditional logit with treaty fixedeffects).
Leinaweaver (2012)	55 environmental agreements (including regional) and 193 countries between 1980 and 2000.	Survival data on ratification recorded annually.	Logit model for survival data with country and treaty random effects.
Bernauer et al. (2013a)	286 agreements, 153 countries between 1973 and 2006.	Survival data on ratification recorded annually.	Cox PH model.
Schulze and Tosun (2013)	21 agreements negotiated under the UNECE. 25 non-EU countries between 1979 and 2010.	Survival data on ratification recorded annually.	Multilevel binary regression for discrete survival model with cross-classified random effects (Cox and logistic regression in appendix).
Cazals and Sauquet (2015)	41 environmental agreements ratification by 99	Survival data on ratification recorded daily.	Cox PH model with frailty term shared at country level.

	countries from 1976 to 1999.		
B¨ohmelt et al. (2015)	250 agreements, 75 democracies between 1973 and 2002. Data from Bernauer et al. (2010).	Survival data on ratification recorded annually.	Logistic regression for survival data.
Mohrenberg et al. (2016)	219 agreements, 160 countries between 1950 and 2000. Data from Bernauer et al. (2010).	Survival data on ratification recorded annually.	Logistic regression for survival data.
Spilker and Koubi (2016)	220 agreements, 162 countries between 1950 and 2000. Data from Bernauer et al. (2010).	Survival data on ratification recorded annually.	Logistic regression for survival data.
Yamagata et al. (2017)	8 agreements and 166 countries between 1981 and 2006.	Survival data on ratification recorded annually.	Two separate logit regressions (pre- and post-1991) for discrete survival analysis. Spatial lag with multiple weighting matrices.
Hugh-Jones et al. (2018)	126 agreements and 157 countries between 1972 and 2000. Bernauer et al. (2010).	Survival data on ratification recorded annually.	Cox PH model stratified on different areas of regulation.
Bellelli et al. (2020)	258 agreements and 192 countries between 1990 and 2015.	Survival data on ratification recorded annually	Cross-classified multilevel discrete survival model with country and treaty random effects estimated with Markow Chain Monte Carlo (MCMC).

13 Concluding remarks

In this appendix, we described the evolution of the three methodological approaches used to empirically study the ratification of environmental agreements. At first, empirical studies use mostly a cross-sectional approach with ratification count data. This approach has numerous limitations, for instance, estimates may be influenced by the cut-off date. Count data models do not allow to explore at the same time country's and treaty's characteristics. Also, the total number of ratification is an opaque measure: does participation in more treaties by a country really imply stronger environmental commitments? The number of ratified agreements largely depends on the number of agreements the country can potentially ratify, a factor that has never been accounted for in this type of studies. The fundamental problem of count data is that it does not allow to identify how countries differ in their ratification choices for the same agreement. Finally, this approach does not cast any light on how ratification by a country interacts with decisions by other countries because these approaches do not use information regarding the timing and hence the sequence of ratification decisions.

Given these limitations, the methodological approach gradually shifted towards the use of survival models. These allow researchers to study both the occurrence and the timing of ratification. We found it useful to distinguish between studies focusing on single agreements and those studying a pooled sample of treaties. Analyses based on the survival approach tackle most of the shortcomings of the previous methodology: it can easily cope with right-censoring, ratifications can be traced to the treaty and country (therefore treaty and country variables can be studied jointly). And importantly, survival analysis allows to study the differences in ratification timing, consequently researcher can study how ratification decisions by different countries interact with each other. However, we note that survival models for large samples of agreements face methodological complexities which are not always appropriately tackled, or even adequately discussed. Above all, pooled survival models need to address the unobserved heterogeneity at the treaty and country level, and ensure the correct identification of potential ratifiers. Unfortunately, we found that in most of the empirical literature to date these issues have been inadequately addressed.

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