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EXPLORING THE NATURE OF STRATEGIC INTERACTIONS IN THE
RATIFICATION PROCESS OF THE KYOTO PROTOCOL

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Résumé / abstract

Do countries interact when they decide to ratify the Kyoto protocol? What is the nature of these possible interactions? To answer these questions we provide a theoretical analysis based on the notions of strategic substitutability and strategic complementarity. Firstly, we analyze the nature of interactions between countries when they merely seek to provide a global public good. Secondly, we argue that countries are interlinked in several dimensions in the real world and we try to shed light on the nature of strategic interactions generated by geographic proximity, trade flows, and green investment flows. The empirical investigation is realized via the estimation of a parametric survival model and our data sample covers the period from 1998 to 2009 for 164 countries. We find evidence that while countries' decision are basically strategic substitutes, they became strategic complements when we focus on the decision of specific peers.

Mots clés /Key words : International Environmental Agreements, Kyoto Protocol, Ratification, Strategic substitutes/complements, Survival model

Codes JEL / JEL codes : C41, F53, H41, Q53, Q56

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1. Introduction

From the third earth summit in Rio 1992, which gathered 172 governments in order to make "the difficult decisions needed to ensure a healthy planet for generations to come" (United Nations (1997)), three conventions were born: the United Nations Framework Convention on Climate Change (UNFCCC), the Convention on Biological Diversity and the United Nations Convention to Combat Desertification. At the present time, only the UNFCCC has given birth to a binding agreement, the Kyoto Protocol (KP). This shows the difficulty of creating such a treaty between sovereign countries and underlines the particular interest we have to understand why do countries participate in this protocol.

Several authors have tried to reveal the role of countries characteristics in the decision to participate in the KP. For instance Neumayer (2002a), studies the role of democracy level. He finds that democracies are more likely to participate in the KP than autocracies, as suggested by Congleton (1992) with respect to International Environmental Agreements (IEA)¹. Then, Fredriksson et al. (2007) and Von Stein (2008) find that the presence of lobby groups affects the probability of ratifying the Kyoto protocol.

However, the question of interdependence in ratification decisions has never been addressed in the literature. Yet, the proceeding of climate change negotiations suggests that this could be relevant. The European heads of governments tried for example to convince Russia to ratify the KP in order to allow the entry into force of the protocol^{2,3}. By contrast in the United States a resolution was adopted by the senators, which stipulated that the US congress was not allowed of ratifying an agreement where the United States would have quantitative emission reduction targets whereas developing countries would not⁴ (Barrett (1998)). Following this announcement, Australia, refused to ratify the KP as well, even though it had initially signed the protocol. This anecdotal evidence suggests

¹Note that Fredriksson and Gaston (2000) find the same results for the ratification of the UNFCCC.

²See among many newspaper articles from the Guardian by Osborn (2001) and from the New York Times by Rohter and Revkin (2004).

³Indeed, to enter into force, the protocol had to be ratified by 55 countries representing 55% of Greenhouse Gas (GHG) in 1990.

⁴The Byrd-Hagel resolution.

that participation in the Kyoto protocol is not an independent decision. Consequently the present paper tries to answer the following questions. Do countries interact when they decide to ratify the Kyoto protocol? What is the nature of these possible interactions?

Even if these questions are not addressed in the literature for the KP case, several authors have tried to measure the presence of interdependencies in environmental treaties participation decisions. [Bernauer et al. \(2010\)](#) study whether the probability of ratification depends on the behavior of similar countries (*e.g.*, belonging to the same region, same income group). However, this is not really a measure of interactions, since only dummy variables are included as proxies of interdependencies. [Davies and Naughton \(2008\)](#) study whether there exists a spatial dependence in the ratification decision process of IEAs. Using a composite index of thirty-seven agreements these authors investigate whether countries from the same area ratify the same number of agreements, rather than really demonstrating an effect of country *j*'s decision on a country *i*'s one. Finally [Beron et al. \(2003\)](#) analyze the ratification of the Montreal protocol. They consider the situation in 1990 and study why countries that ratified the protocol before 1990 did so. They do not find interdependence in the ratification process. However, on the one hand, they make a cross section analysis, and if there are interactions, they take place over time. On the other hand, they study the Montreal protocol and we are not sure that the participation of countries in this treaty can be analyzed as a cooperative behavior. Indeed, [Murdoch and Sandler \(1997\)](#) explain that the use of CFC substitutes was probably economically profitable.

Therefore, according to our knowledge, there is no study measuring precisely the presence or absence of interactions between States when they decide to participate in an IEA, neither for the Kyoto Protocol nor for any other one. Consequently, our contribution to the literature is to empirically evaluate the presence of interactions between the ratification decisions⁵, and this is done for a major binding agreement, the Kyoto protocol.

⁵Although signature is not a meaningless act, ratification is more interesting to study, since according to the UN definition "upon ratification, the State becomes legally bound under the treaty" ([United Nations, 2006](#)). See also [Barrett \(1998\)](#) for a description of the different stages of a treaty-making.

The theoretical analysis is based on the notions of strategic substitutability and strategic complementarity. We argue that countries are interlinked in several dimensions in the real world, and try to shed light on the nature of interactions generated by geographic proximity, trade flows and green investments flows.

The empirical investigation is realized via the introduction of a spatially lagged endogenous variable into a duration model and our data sample covers the period from 1998 to 2009. We find evidence that the decisions of neighbors, trade partners, and of green investors matter.

The rest of the paper is organized in the following manner. We analyze the multiple dimensions influencing the negotiation of an IEA in Section 2. Then, in Section 3 we explain how we measure the factors affecting a State decision and we present our estimator. Our results are analyzed in Section 4 and finally, in Section 5, we conclude.

2. Analysis of the multiple dimensions at stake

The interaction between a country and its peers can evolve in two directions. The utility of a country's contribution to the public good may either (i) decrease with the contribution of its peers, the contributions thus being strategic substitutes; or (ii) increase with the contribution of its peers, the contributions thus being strategic complements. In this paper, the contribution to the public good considered is the ratification of a country⁶. We first analyze the likely nature of contributions when a country merely seeks to provide a global public good. Then, we consider that the ratification could be motivated by other considerations such as neighbor relations, trade relations and the willingness to host sustainable development projects such as Clean Development Mechanism (CDM) ones.

2.1. Public good provision

Let us first study how a country is influenced by its peer's decisions when it merely seeks to provide a global public good, namely avoiding climate change. Consider the

⁶Indeed, we try to understand why countries participate in the KP, not to explain their level of participation. The latter would have been measured by the decrease in GHG's emissions to which they committed themselves. For a study on participation level in IEA, see for example [Bratberg et al. \(2005\)](#).

utility function of a country i represented by $U_i(x_i, G)$, where x is the private good and G the public good. The country chooses to allocate its resources to the provision of the private good (x_i) or to the provision of the public good (contribution = g_i). Since in the specific context of climate change, the emission of z tonnes of carbon has the same impact whoever emits them, the aggregation technology of contributions is the summation, therefore $G = g_i + \sum_{j \neq i} g_j$. This implies that i 's contribution and rest-of-world contributions are strategic substitutes (see [Cornes and Sandler \(1996\)](#), p. 144 and [Sandler \(1998\)](#)). Thus countries will have incentives to let others reduce GHG's emissions, *i.e.*, to free-ride. This leads us to us to make our first hypothesis.

Hypothesis 1. *The ratification utility of a country i is a decreasing function of the participation of the other countries, *i.e.*, participation decisions are strategic substitutes.*

Without considering any other participation determinants, it is difficult to explain the formation of an agreement concerning climate change. As underlined by [Glazer and Proost \(2008\)](#), the free rider problem should deter participation. Furthermore, a large number of theoretical works predict that environmental agreements gathering a relatively large number of countries are not stable (see [Finus et al. \(2006\)](#) for a literature review on this question).

However, we do observe a rise in IEAs. According to [Mitchell \(2003\)](#), more than 700 multilateral agreements and 1000 bilateral agreements would exist. Therefore, we argue that ratification could be motivated by other considerations than the provision of a global public good and we study these alternative motivations in the next subsection.

2.2. Additional dimensions

“If a small group of people who have an interest in a collective good happened also to be personal friends, or belonging to the same social club, and some of the group left the burden of providing that collective good on others, they might, even if they gained economically by this course of action, lose socially by it...” Olson 1965, p. 64.

In the real world, countries are interlinked in several dimensions, which could lead them to act as members of a social group. Therefore, a country does not attach the same importance to each ratification according to the links it has with the country that ratified

the agreement. Indeed, as pointed out by [Guzman \(2008\)](#), the participation of a country in an IEA has external consequences. For instance, it could be viewed as a cooperative signal affecting other dimensions such as diplomatic and trade relations. Moreover it can be considered that the design of the treaty affects the influence of a country on another, for example through the green investment flows ensuing from the Clean Development Mechanism.

2.2.1. The effect of proximity

Geographical proximity often implies cultural similarity, social proximity and economic interdependencies which result in repeated interactions between countries. This is the first idea advanced by [Gleditsch and Ward \(2001\)](#): “*Distance is widely acknowledged to be a primary force shaping the opportunity for interaction among states in the international system.*”. This results in diplomatic relations of the utmost importance and leads states to participate in IEA even though they do not have immediate incentives or economic interests to do it. [Maler \(1990\)](#) highlights a meaningful example that illustrates this point. He describes the Columbian River Treaty between the US and Canada concerning hydropower generation and flood protection. The negotiations ended with a gain of about \$250 million for Canada and a loss of about \$300 for the United States, one of the US negotiators adding that the growth of Canada was of primary importance for the US.

We argue that strong diplomatic ties between neighboring countries could lead them to ratify an unprofitable environmental agreement in order to maintain those ties. Therefore, we expect a country will be positively affected by the decision of neighboring countries.

Hypothesis 2. *Ratification utility of country i and that of its neighbors are strategic complements.*

2.2.2. The importance of trade

Consider now a more economic interdependence, such as the one created by trade flows. As pointed out by [Neumayer \(2002b\)](#), we are in a world where we consider that imports benefit mainly the exporter. Therefore a country aspires to creating and maintaining a good reputation within the international community if it does not want to face trade restrictions. In this context, participation in an IEA constitutes a positive signal that

enhances a country's reputation⁷. This positive signal is also important if a country seeks to benefit from new preferential trade agreements. On the other side, several countries are scared that the Kyoto protocol will hamper their competitiveness. The attitude of the US senate described in the introduction is now a classic example but the New-Zealand case is an interesting one too. Yang (2004) detailed the conflict between the Labour-led government and the business lobby. The former wanted a ratification as soon as possible while the latter argued that "New Zealand's ratification of the Protocol should be conditioned on its major trading partners' ratification."

The three effects described, avoiding trade restrictions, reaching new trade agreements and avoiding relative competitiveness loss could drive countries to follow the decisions of their trading partners. This leads us to formulate our third hypothesis⁸.

Hypothesis 3. *Ratification utility of country i and that of its trading partners are strategic complements.*

2.2.3. The CDM role

When a developed country ratifies the Kyoto protocol, it is registered as an Annex 1 country and therefore receives emission reduction targets. To meet these targets, a country can decrease its carbon emissions on its own territory or resort to flexibility mechanism such as the Clean Development Mechanism⁹. The main rules governing this mechanism have been defined at the COP 7 held in Marrakesh in 2001 (Lecocq and Ambrosi, 2007). The principle is to finance an emission-reduction project in a developing country, which can lead to the creation of saleable certified emission reduction credits¹⁰. On the one hand, this mechanism confers to developed countries a more flexible way to meet their targets. On the other hand, it constitutes a great opportunity for developing countries as

⁷As shown by Egger et al. (2011) for the case of trade and Rose and Spiegel (2009) for the case of access to credits.

⁸Note that strategic complementarity may also occur in GHGs emission fall, as shown by Copeland and Taylor (2005).

⁹The study of the Joint Implementation mechanism is of limited interest since it began with the first commitment period in the KP in 2008 (Grubb et al. (2011)).

¹⁰Each of them is equivalent to one tonne of CO₂ and these credits can be used to meet the Kyoto targets (UNFCCC, 2011).

well. Indeed one objective of the CDM was to promote sustainable development, through the financing of new projects and the technological transfers which might ensue¹¹. To host a CDM project, the developing country obviously had to ratify the KP first. Therefore we expect that the ratification decision of a developing country will follow that of the developed countries that will fund the CDM projects on its territory.

Hypothesis 4. *Ratification utility of country i and that of the country funding CDM projects in its own territory are strategic complements.*

3. Empirical strategy

3.1. Data and Measures

To test the hypothesis formulated in the preceding section, we estimate an equation of the following form :

$$r_{it} = \kappa \sum_{i \neq j} r_{jt} + \vartheta \sum_{i \neq j} \omega_{ij} r_{jt} + \sum_k \zeta_k X_{kit} + \eta_{it}.$$

The dependent variable r_{it} takes the value of 1 if country i ratifies during the year t (as reported by the UNFCCC) and 0 otherwise. The influence of the participation of other countries j on a country i (the external determinants of ratification) is captured through the parameters κ and ϑ . A set of k control variables X is introduced of which influence is captured through the ζ_k parameters. These control variables represent the internal determinants of the KP ratification, namely the country's characteristics. η_{it} is the remaining error term. Our data sample covers the period from 1998 to 2009 for 164 countries. A comprehensive list of the variables, along with their definitions and sources is available in the table 1 of the Appendix.

The parameter κ allows us to study the reaction of a country when the number of countries engaged ($\sum_{i \neq j} r_{jt}$) increases (variable "Number_ratifications"). This will help us to find out whether there is a free rider problem (driven by a substitutability in ratification decisions) or not.

¹¹See [Dechezleprêtre et al. \(2008, 2009\)](#) for a study of the characteristics of these technological transfers.

Then, in order to study strategic complementarities or substitutabilities in ratification decisions in the three additional dimensions described in our theoretical analysis, we borrow the methodology used in the tax-competition and public spending literature (see [Brueckner \(2003\)](#)). We estimate a spatial-lag model, where the spatially lagged endogenous variable (thereafter "spatial lag") is of the form $\sum_{i \neq j} \omega_{ij} r_{jt}$. The weighting factor used ω_{ij} measures the intensity of the links between countries i and j and is obviously specific to each studied dimension. To be able to compare our coefficients between the models, our weights are normalized (they range from 0 to 100). Their main descriptive statistics can be found in the table 4 of the Appendix.

To evaluate the influence of the decision of neighbors, ω_{ij} is defined as $\frac{\frac{1}{d_{ij}^2}}{\sum_{i \neq j} \frac{1}{d_{ij}^2}} * 100$ where d_{ij} is the distance between i 's and j 's capital provided by the CEPII distance database.

Second, bilateral export flows allows us of estimating the effect of the decision of trading partners on the decision of a country. ω_{ij} is therefore defined as $\frac{X_{ij}}{\sum_{i \neq j} X_{ij}} * 100$, where X_{ij} is the percentage of exports from i to j ¹². The weighting factor ω_{ij} corresponds to the part of exports from i to j in the total exports of i .

Our third weighting factor is the number of registered CDM projects financed by a developed country j in a developing country i , listed in the CDM pipeline UNEP-RISOE database from 1998 to 2009. Therefore ω_{ij} is defined as $\frac{P_{ij}}{\sum_{i \neq j} P_{ij}} * 100$, where $\sum_{i \neq j} P_{ij}$ is the total number of registered projects in a hosting country at the end of the sample period.

Lastly, following [Case et al. \(1993\)](#) and [Lockwood and Migali \(2009\)](#), we construct a "placebo" weighting scheme that will ensure that the results are not driven by model misspecification such as omitted common shocks. This weight is constructed as follows: we consider that the first and last countries in alphabetical order are linked (ω_{ij} taking the value of one), then the second and the second last are considered as linked too and so on. We obviously expect a non significant coefficient associated with this spatially lagged

¹²We exploit export data from the UN Comtrade database and X_{ij} is the mean of available bilateral exports for the sample period.

term.

The set of internal determinants includes first the quality of institutions. A country is considered as “Free” (=3) if the sum of its civil liberty index and its political right index is below 5 , “Non-Free” (=1) if it is above 10 and “Partly-Free” (=2) otherwise (variable “Democracy”). Data comes from the Freedom House. Since the ratification of European Union countries was a joint decision, we introduce a dummy when the country was a member of the EU in 2002 (variable “EU”). We also introduce a dummy variable for Annex 1 countries (“Annex_1”). The other characteristics of countries are taken from the World Bank Development Indicator 2010. We introduce the education level of a country, measured by the rate of gross secondary school enrollment (“Education”). We introduce the GDP per capita and its squared term in order to take into account the environmental kuznets curve effect (“GDPpercap” and “GDPpercap²”). Finally, following Neumayer (2002b) and Fredriksson et al. (2007), we introduce the ratio of fuel exports on total export, in order to take into account the lobbying that governments could face (“OilExports”).

3.2. Duration issues

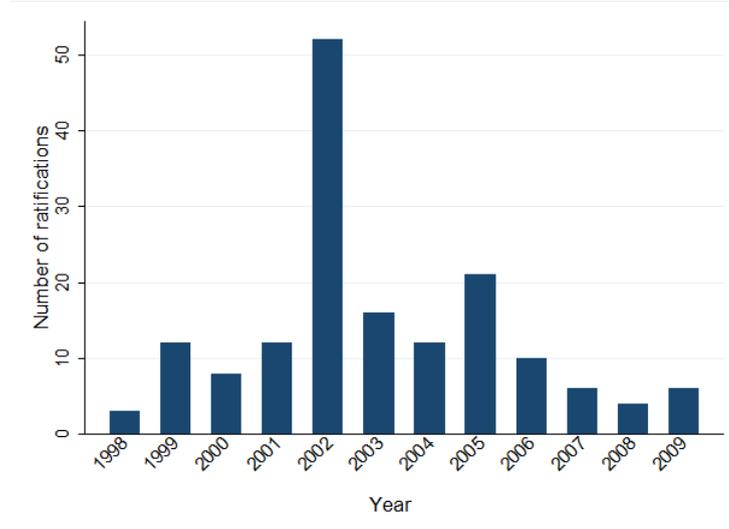
We try to explain the number of years a country takes to ratify the KP from its opening to ratification in 1998. This requires the use of a duration model. The main advantage of this kind of model is that the individuals could be observed on different sample periods and we can take into account of censor in the sample. In our case, we observe some countries until 2002 (*e.g.*, the EU15 members) and some until 2009, since they never ratified the KP (*e.g.*, the United States)¹³.

Since we observe yearly ratifications, our scale time is non-continuous and we are in the case of grouped data. Indeed, as shown by figure 1, the KP is ratified by 17 countries per year on average, with a peak of 54 in 2002¹⁴.

¹³Technically, we are in the case of single spell data (only one ratification per country) with a right-censored sample (some countries have not yet ratified the KP at the end of the studied period).

¹⁴This peak can be explained by the adoption of the CDM mechanism through the Marrakesh accords in 2001.

Figure 1: Number of countries ratifying the Kyoto protocol by year, from 1998 to 2009.



Therefore, we are confronted with multiple time failure problems, which makes semi-parametric models like the Cox proportional hazards one inaccurate (see [Woolldridge \(2001\)](#)). This leads us to use a parametric survival model.

The general formulation of a parametric survival model in the proportional hazard metric is as follows:

$$h(t|x_p) = h_0(t)exp(x_p\beta_x), \quad (1)$$

where t is the time scale, p the unit of observation and x a matrix of both variant and time invariant independent variables and β_x the corresponding coefficients. The hazard rate ($h(t|x_p)$) is the probability that a country i ratifies ($r_{it} = 1$) during the next period, considering that it has not ratified yet. The baseline hazard $h_0(t)$ is the probability to ratify that everyone faces, this latter being modified by the value of the x_p , specific to each individual.

The estimation of a parametric survival model drives us to make an assumption about the baseline hazard distribution $h_0(t)$. Note that this latter is the counterpart of the error term in standard regressions. The two terms will be used interchangeably in the rest of the paper. From a theoretical point of view, any law representing the distribution of a positive variable can be used to model the distribution of the baseline hazard. Therefore we

calculate the Akaike information criterion¹⁵, widely used in order to discriminate between the different available laws, to choose between a Weibull, Gompertz, log-normal or log-logistic distribution of the baseline hazard. As found by [Fredriksson et al. \(2007\)](#), the hazard rate of the KP ratification process seems to be best represented by a Weibull or Gompertz distribution, which imply a monotonous evolution of the hazard¹⁶.

Furthermore, since we have panel data, this allows of controlling for the unobserved heterogeneity specific to each individual. In survival models, this becomes possible with the introduction of a frailty term in the model. In a formal form the unshared frailty model can be represented as follows:

$$h(t_p|x_p, \alpha_p) = \alpha_p h(t_p|x_p), \quad (2)$$

where α_p is an unobserved observation-specific effect ([Cleves et al. \(2010\)](#))¹⁷. By specifying a frailty term shared at the country level, we obtain a model analogous to a random-effect model in panel data regressions ([Gutierrez \(2002\)](#)). Our main results will therefore come from the estimation of parametric survival models with a frailty term shared at the country level.

The shared frailty model can be written as:

$$h(t_{fp}|x_{fp}, \alpha_f) = \alpha_f h(t_{fp}|x_{fp}), \quad (3)$$

where f identifies the group of N observations of the same frailty. This model is estimated using maximum likelihood.

¹⁵The Akaike information criterion can be defined as $AIC = -2\ln L + 2(\alpha + \beta)$, where L is the log-likelihood of the estimation, α the number of explanatory variables and β the number of specific distributions.

¹⁶The Weibull baseline hazard function is equal to pt^{p-1} and the Gompertz hazard function to $exp(\gamma t)$, where t is the time in year and p and γ the respective shape parameters ([Cleves et al. \(2010\)](#)).

¹⁷The distribution of the frailty parameters chosen for its mathematical tractability is the inverse-gaussian one. The frailty is assumed to have mean 1 and variance θ for model identifiability.

3.3. Spatial issues

To measure interdependencies in the ratification process of the Kyoto Protocol, we introduce a spatially lagged endogenous variable in a parametric duration model. This methodology is similar to the one used by [Simmons and Elkins \(2004\)](#) in their study of the spread of liberalization across countries. However, as discussed by [Anselin \(1988\)](#), we could be facing two problems ; endogeneity, and spatial error correlation. These two issues can be treated through GMM or maximum likelihood estimation in linear models (see [Brueckner \(2003\)](#)). Yet, there is no proper "spatial estimator" for survival model and it is not the scope of this paper to develop such an estimator. However, being aware that our model could be subject to the spatial error correlation problem, we develop several strategies to cope with it.

The presence of spatial error correlation would mean that the model is misspecified and that there is a correlation between our error terms which would threaten the properties of the estimator (see [Anselin \(2006\)](#)). Therefore, first, we carefully specify our model and then, we allow for correlation between the error terms in several manners. We cannot estimate a proper spatial error correlation in the way [Darmofal \(2009\)](#) and [Banerjee et al. \(2003\)](#) do. These authors implement (bayesian) parametric spatial survival models, but this kind of model only exists for cross-section data. In our case, interactions take place over time and so it is not relevant to investigate them in a cross section setting. That is the reason why we decide to control for potential correlation between the error terms while keeping both our temporal and individual dimensions.

Our strategy is to run estimations while allowing for correlation between the error terms in several manners. If the results vary according to the type of spatial correlation allowed by the model, then misspecification can be suspected. The easiest situation in which we could relax the assumption of no error correlation is the case where our weighting factor is the distance between capitals. In this case, we can think that, if there is a correlation between the error terms, it mainly occurs in a particular geographic area. Therefore, we first allow for a correlation between the error terms by specifying a cluster

at the continent level and at the World-Bank regions level¹⁸. To ensure the robustness of our results, we also specified a frailty model where the frailties are shared at the continent level and the World-Bank regions level.

4. Determination of the nature of interactions

4.1. Main results

As mentioned, our data sample covers the period from 1998 to 2009 for 164 countries. Descriptive statistics on the independent variables are available in Appendix, table 3 and 4, and the list of countries included in the sample is in table 5. A preliminary examination of the descriptive statistics on the dependent variable available in table 2, shows that 84% of the countries present in our sample ratified the Kyoto protocol before the end of the period studied, and the median country ratifies 5 years after the opening of the protocol to ratification.

We present our main estimation results in table 6. In column (1) the weighting factor is the distance between capitals, in column (2) the bilateral export flows, in column (3) the number of hosted CDM projects, and in column (4) we used our placebo weight. Finally, since we presented the parametric survival model in the proportional hazard metric form, hazard ratios are reported.

[insert table 6 here]

First, we find a robust influence of the democracy level and of the oil-lobbies. We observe that the probability of ratification increases with the democracy level, which is consistent with former studies (see [Fredriksson and Gaston \(2000\)](#), [Neumayer \(2002a,b\)](#)). The power of the oil-lobbies seems to impede the participation as found by [Fredriksson et al. \(2007\)](#) and [Neumayer \(2002b\)](#). The coefficients associated with the EU and Annex_1 dummy variables are as expected. On the one hand, the EU-countries ratified sooner than

¹⁸The World Bank classifies the countries in 7 regions that do not correspond exactly to the geographic continents. For example we have: "Middle East & North Africa" and "Sub-Saharan Africa". Note that the developed countries belong to the same region.

the others, which confirms their leader status. On the other hand, Annex-1 countries show some reluctance to ratify compared to the Non-Annex 1 countries, which is not surprising since the former face quantitative mitigation constraints whereas the latter do not.

Then, the coefficient associated with the number of involved countries is below 1 and significant. According to our first hypothesis, this result indicates that the ratification process of the Kyoto protocol is subject to a free rider problem. Therefore, ratification decisions seem to be basically strategic substitutes.

However, specifications (1), (2) and (3) indicate that when we take into account the interactions with our geographic neighbors, our trade partners or with countries financing CDM projects, the ratification decisions are strategic complements. Indeed the coefficient associated with the spatial lag is above 1 and significant for the three dimensions studied. Hypothesis 2, 3 and 4 are therefore not rejected by the estimations. Finally, as expected, the coefficient associated with the spatial-lag created thanks to our placebo matrix is non significant which removes doubts on a potential significance bias of our estimator.

Therefore, we find that even if the ratification of the KP is subjected to a free rider problem, when we study additional dimensions such as geographic networks, trading relations and the willingness to attract green financing, the ratification decisions are strategic complements.

4.2. Robustness checks

To check the strength of our results, we implement several robustness tests. Firstly, we relax the no spatial error correlation assumption, as explained in section 3.3. Secondly, we change the ratification year definition. Moreover, to ensure that our results do not depend of the distribution law choosen, we model the baseline hazard through a weibull law in the first series of robustness checks and as a gompertz law in the second one.

Spatial error correlation

We first control the robustness of our results by allowing a correlation between error terms. In columns (1) of table 7 we specify a frailty at the World Bank regions level, in column (2) a frailty at the continent level and in columns (3) and (4) we clusterize our

error terms at the same respective levels. We compare the result to those found in column (1) of table 6 (results also reported in column (a) of the present table 7).

[insert table 7 here]

As we can see, our results are strongly robust to various alternative specifications allowing for a correlation of the error terms at the geographic level. Regarding the external determinants, the significance of the coefficients associated to the spatial-lag term remains unchanged, and the magnitude of these coefficients varies only very slightly. This is also true for the number of involved countries.

These robustness checks, therefore, allow of rejecting misspecification generated by spatial autocorrelation problem and the omission of important control variables.

Time definition

The ratification of the protocol is officially validated on a specific date. Therefore when we consider that two countries have ratified the protocol during year t , there could be 364 days between their ratifications. It is then interesting to take a different definition of the ratification year. As a second kind of robustness check, we therefore consider that a country ratifies at time t if it has ratified between the 1st of July of year $t - 1$ and the 30th of June of year t . We reestimated the same equations presented in table 6 and present our new results in table 8.

[insert table 8 here]

As our estimates show, our results are robust to the change in the ratification year definition. Both magnitude and significance of the coefficients are comparable to the ones found in tables 6 and 7. We therefore consider that our results are robust¹⁹.

¹⁹We also consider a third definition of the ratification year. We consider that a country ratifies at time t if it ratifies between the 16th of March of year t and the 15th of March of year $t + 1$, since the first signature was on the 16th of March 1998. Our results are also robust to this modification. Finally, when we do not normalize our spatial weight, the significance of the coefficients remains unchanged. Results are available upon request.

5. Concluding remarks

The purpose of this paper was to examine the interactions between the decisions to ratify an international environmental treaty such as the Kyoto protocol. We proposed an analysis of the nature of interactions between countries, followed by an empirical investigation based on the Kyoto protocol ratification timing.

The findings of this paper have implications both for the theoretical study of the formation of international environmental agreements and for the design of new agreements. Indeed, there are interactions between countries and they cannot be ignored.

Through our empirical analysis, we found evidence of free riding behavior, which is consistent with the nature of the public good provided. However, we showed that when we study the influence of specific countries, such as geographic neighbors, trading partners or green investors, the decision of a country and that of its partners are strategic complements.

Our results imply that the nature of the dilemma countries face when dealing with climate change, could be altered by the multiple links between countries, *i.e.*, that an agreement gathering a large number of countries can be reached even if it is basically subject to a free rider phenomenon.

The next question is how to use the links revealed to increase the participation in IEAs. One solution would be to move towards the creation of a multiple treaties system such as technology-environment or trade-environment agreements, as pointed by [Folmer et al. \(1993\)](#). The tendency to follow the decision of our trade partners raises also the potential to use commercial sanctions to ensure compliance, as suggested by [Barrett \(2003, 2011\)](#)²⁰.

To conclude, this article proposes a framework to understand the formation of International Environmental Agreements. It sheds light on important dimensions that should not be ignored if we want to build a treaty gathering a large number of participants.

²⁰Note however that this could break-up the domino effect in the participation decisions observed.

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Appendix

Table 1: Source and definition of the variables

| Variable | Definition | Source |
|------------------------------------|---|----------------------------------|
| Dependent variable | | |
| Ratification (r_{it}) | Dummy variable equal to 1 if country i ratifies during year t . | UNFCCC website |
| Spatial lag weights | | |
| Proximity | Distance in kilometers between two capitals. | CEPII |
| Trade | Mean of available bilateral exports flows for the sample period, in current dollars. | UN Comtrade |
| CDM | Number registred CDM projects from 1998 to 2009. | UNEP-RISOE database |
| Internal Factors | | |
| Democracy | The country is considered as "Free" (=3) if the sum of its civil liberty index and its political right index is below 5 , "Non-Free" (=1) if it is above 10 and "Partly-Free" (=2) otherwise. | Freedom House |
| GDPpercap / GDPpercap ² | Logarithm of GDP per capita, in PPA, dollars 2000. | World Development Indicator 2010 |
| OilExports | Ratio of fuel exports on total exports. | World Development Indicator 2010 |
| Education | Gross secondary school enrollment in percent. | World Development Indicator 2010 |
| Annex_1 | Dummy variable equal to 1 if a country is registered on the Annex_1 of the Kyoto Protocol. | UNFCCC website |
| EU | Dummy variable equal to 1 if the country was a member of the European Union in 2002. | Portail de l'Union Européenne |

Table 2: Ratification timing description

| Category | total | <i>(Per subject)</i> | | | |
|--------------------|-------|----------------------|-----|--------|-----|
| | | mean | min | median | max |
| Nb. of subjects | 164 | | | | |
| Nb. of records | 735 | 4.48 | 1 | 4 | 12 |
| (first) entry time | | 0 | 0 | 0 | 0 |
| (final) exit time | | 5.65 | 1 | 5 | 12 |
| failures | 138 | 0.84 | 0 | 1 | 1 |

Table 3: Descriptive statistics on the independent variables

| Variable | Mean | Std. Dev. | Min | Max |
|-----------------------------------|----------|-----------|---------|----------|
| GDPpercap (in level) | 6049.21 | 9232.55 | 80.62 | 48485.15 |
| GDPpercap ² (in level) | 1.22e+08 | 2.99e+08 | 6500.33 | 2.35e+09 |
| Democracy | 2.03 | 0.925 | 0 | 3 |
| EU | 0.09 | 0.28 | 0 | 1 |
| Education | 70.23 | 33.89 | 5.18 | 161.78 |
| OiLexports | 17.77 | 29.64 | 0 | 99.66 |
| Annex_1 | 0.26 | 0.44 | 0 | 1 |

Table 4: Descriptive statistics on the spatially lagged variables

| Weighting factor | Mean | Std. Dev. | Min | Max |
|------------------|-------|-----------|-----------|-------|
| Distance | 24.98 | 23.25 | 0.2574998 | 93.36 |
| Trade | 28.04 | 34.99 | 0 | 99.01 |
| CDM | 9.32 | 28.62 | 0 | 100 |
| Placebo | 32.30 | 46.80 | 0 | 100 |

Table 5: List of countries

| 164 countries included in the estimation sample | | | | |
|---|--------------------|--------------------|--------------------|----------------------------|
| Albania | Comoros | Hungary | Mauritius | South Africa |
| Algeria | Congo, Dem. Rep. | Iceland | Mexico | Spain |
| Angola | Congo, Rep. | India | Moldova | Sri Lanka |
| Argentina | Costa Rica | Indonesia | Mongolia | St. Kitts and Nevis |
| Armenia | Cote d'Ivoire | Iran, Islamic Rep. | Morocco | St. Lucia |
| Aruba | Croatia | Iraq | Mozambique | St. Vinc. & the Grenadines |
| Australia | Cyprus | Ireland | Namibia | Sudan |
| Austria | Czech Republic | Israel | Nepal | Suriname |
| Azerbaijan | Denmark | Italy | Netherlands | Swaziland |
| Bahamas, The | Djibouti | Jamaica | New Zealand | Sweden |
| Bahrain | Dominica | Japan | Nicaragua | Switzerland |
| Bangladesh | Dominican Republic | Jordan | Niger | Syrian Arab Republic |
| Belarus | Ecuador | Kazakhstan | Nigeria | Tanzania |
| Belgium | Egypt, Arab Rep. | Kenya | Norway | Thailand |
| Belize | El Salvador | Kiribati | Oman | Togo |
| Benin | Equatorial Guinea | Korea, Rep. | Pakistan | Tonga |
| Bhutan | Eritrea | Kuwait | Panama | Trinidad and Tobago |
| Bolivia | Estonia | Kyrgyz Republic | Paraguay | Tunisia |
| Bosnia and Herzegovina | Ethiopia | Lao PDR | Peru | Turkey |
| Botswana | Fiji | Latvia | Philippines | Uganda |
| Brazil | Finland | Lebanon | Poland | Ukraine |
| Brunei Darussalam | France | Lesotho | Portugal | United Arab Emirates |
| Bulgaria | Gabon | Liberia | Romania | United Kingdom |
| Burkina Faso | Gambia, The | Libya | Russian Federation | United States |
| Cambodia | Georgia | Lithuania | Rwanda | Uruguay |
| Cameroon | Germany | Luxembourg | Samoa | Uzbekistan |
| Canada | Ghana | Macedonia, FYR | Saudi Arabia | Vanuatu |
| Cape Verde | Greece | Malawi | Senegal | Venezuela, RB |
| Central African Republic | Grenada | Malaysia | Seychelles | Vietnam |
| Chad | Guatemala | Maldives | Sierra Leone | Yemen, Rep. |
| Chile | Guinea | Mali | Slovak Republic | Zambia |
| China | Guinea-Bissau | Malta | Slovenia | Zimbabwe |
| Colombia | Guyana | Mauritania | Solomon Islands | |

Tables

Table 6: Estimation results of the probability to ratify the KP

| <i>Weighting factor</i> | Proximity | Trade | CDM | Placebo |
|------------------------------|-------------------------|-------------------------|------------------------|-------------------------|
| | (1) | (2) | (3) | (4) |
| <i>Internal determinants</i> | | | | |
| GDPpercap | 2.962798 (0.110) | 2.874845 (0.312) | 3.753462* (0.054) | 3.119267* (0.094) |
| GDPpercap ² | 0.9335409 (0.105) | 0.9499714 (0.432) | 0.9201849* (0.050) | 0.9286307* (0.079) |
| Democracy | 1.462863*** (0.004) | 1.546854** (0.034) | 1.526644*** (0.001) | 1.514815*** (0.001) |
| Education | 1.001987 (0.691) | 0.9917784 (0.335) | 0.9983253 (0.745) | 1.000052 (0.992) |
| Oil_exports | 0.9905073** (0.019) | 0.9821247** (0.012) | 0.9939804 (0.112) | 2.185087** (0.042) |
| EU | 2.345273** (0.024) | 1.503324 (0.499) | 2.090881* (0.054) | 0.9937211* (0.095) |
| Annexe_1 | 0.4178973*** (0.006) | 0.3891647** (0.047) | 0.7407765 (0.313) | 0.6161668* (0.097) |
| <i>External determinants</i> | | | | |
| Number_ratifications | 0.9568314*** (0.000) | 0.9006794*** (0.000) | 0.966805*** (0.000) | 0.9702445*** (0.000) |
| Spatial lag | 1.031403*** (0.000) | 1.057794*** (0.000) | 1.006997*** (0.002) | 1.001502 (0.449) |
| Distribution law | Weibull | Gompertz | Weibull | Weibull |
| Shape parameters | 1.73895 | 1.50853 | 6.180369 | 5.809015 |
| theta | 6.37e-08 | 1.612494 | 2.97e-08 | 2.97e-08 |
| Nb. Countries | 164 | 129 | 164 | 164 |
| Nb. Obs. | 735 | 579 | 735 | 735 |

Notes: ***=significant at the 1 percent level, **=significant at the 5 percent level, *=significant at the 10 percent level. *p*-values associated to the reported coefficients (hazard-ratios) and test statistics are in parentheses. The shape parameters refer to the distribution law of the baseline hazard and θ characterise the distribution of the frailty term.

Table 7: Weibull estimation results with different forms of spatial error correlation allowed

| <i>Specification</i> | Proximity | Frailty WB | Frailty continent | Cluster WB | Cluster continent |
|------------------------------|------------------------|------------------------|--------------------------|------------------------|--------------------------|
| | (a) | (1) | (2) | (3) | (4) |
| <i>Internal determinants</i> | | | | | |
| GDPpercap | 2.962798 (0.110) | 2.962869 (0.110) | 2.962912 (0.110) | 2.962869 (0.116) | 2.962869 (0.110) |
| GDPpercap ² | 0.933541 (0.105) | 0.93354 (0.105) | 0.933539 (0.105) | 0.93354 (0.105) | 0.93354 (0.105) |
| Democracy | 1.462863*** (0.004) | 1.462872*** (0.004) | 1.462871*** (0.004) | 1.462872*** (0.001) | 1.462872*** (0.000) |
| Education | 1.001987 (0.691) | 1.001987 (0.691) | 1.001987 (0.691) | 1.001987 (0.652) | 1.001987 (0.395) |
| OilExports | 0.990507** (0.019) | 0.990507** (0.019) | 0.990507** (0.019) | 0.990507*** (0.004) | 0.990507*** (0.000) |
| EU | 2.345273** (0.024) | 2.345184** (0.024) | 2.345195** (0.024) | 2.345184** (0.030) | 2.345184*** (0.005) |
| Annexe_1 | 0.417897*** (0.006) | 0.417893*** (0.006) | 0.417896*** (0.006) | 0.417893*** (0.000) | 0.417893*** (0.001) |
| <i>External determinants</i> | | | | | |
| Number_ratifications | 0.956831*** (0.000) | 0.956832*** (0.000) | 0.956832*** (0.000) | 0.956832*** (0.001) | 0.956832*** (0.001) |
| Spatial lag | 1.031403*** (0.000) | 1.031404*** (0.000) | 1.031404*** (0.000) | 1.031404*** (0.000) | 1.031404*** (0.002) |
| Distribution law | Weibull | Weibull | Weibull | Weibull | Weibull |
| Shape parameters | 1.73895 | 1.738943 | 1.738941 | 1.738943 | 1.738943 |
| θ | 6.37E-08 | 2.2E-08 | 2.29E-08 | - | - |
| Nb. Countries | 164 | 164 | 164 | 164 | 164 |
| Nb. Obs. | 735 | 735 | 735 | 735 | 735 |

Notes: ***=significant at the 1 percent level, **=significant at the 5 percent level, *=significant at the 10 percent level. *p*-values associated to the reported coefficients (hazard-ratios) and test statistics are in parentheses. The shape parameters refer to the distribution law of the baseline hazard and θ characterise the distribution of the frailty term.

Table 8: Gompertz estimation results with modification of the ratification year definition

| <i>Weighting factor</i> | Proximity | Trade | CDM | Placebo |
|------------------------------|------------------|--------------|-------------|----------------|
| | (1) | (2) | (3) | (4) |
| <i>Internal determinants</i> | | | | |
| GDPpercap | 5.814664* | 4.596807 | 5.962287** | 6.419279** |
| | (0.057) | (0.131) | (0.043) | (0.042) |
| GDPpercap ² | 0.89487* | 0.921379 | 0.894776** | 0.887575** |
| | (0.057) | (0.195) | (0.044) | (0.038) |
| Democracy | 1.76145*** | 1.606737** | 1.761894*** | 1.779437*** |
| | (0.001) | (0.019) | (0.001) | (0.001) |
| Education | 0.999344 | 0.987119 | 0.995362 | 0.997963 |
| | (0.921) | (0.114) | (0.467) | (0.755) |
| Oil_exports | 0.989613* | 0.989055* | 0.992963 | 0.991479* |
| | (0.055) | (0.084) | (0.153) | (0.098) |
| EU | 3.703739** | 1.736672 | 3.104881** | 3.551775** |
| | (0.014) | (0.342) | (0.021) | (0.016) |
| Annexe_1 | 0.350785** | 0.430119* | 0.641026 | 0.46128* |
| | (0.017) | (0.062) | (0.254) | (0.053) |
| <i>External determinants</i> | | | | |
| Number_ratifications | 0.936296*** | 0.895524*** | 0.935424*** | 0.944028*** |
| | (0.000) | (0.000) | (0.000) | (0.000) |
| Spatial lag | 1.023107** | 1.04094*** | 1.01217*** | 1.002163 |
| | (0.031) | (0.000) | (0.000) | (0.388) |
| Distribution law | Gompertz | Gompertz | Gompertz | Gompertz |
| Shape parameters | 1.628741 | 1.822881 | 1.8028 | 1.665023 |
| θ | 0.947651 | 1.156995 | 0.574599 | 0.835736 |
| Nb. Countries | 164 | 129 | 164 | 164 |
| Nb. Obs. | 809 | 643 | 809 | 809 |

Notes: ***=significant at the 1 percent level, **=significant at the 5 percent level, *=significant at the 10 percent level. *p*-values associated to the reported coefficients (hazard-ratios) and test statistics are in parentheses. The shape parameters refer to the distribution law of the baseline hazard and θ characterise the distribution of the frailty term.