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Climate Agreement and Technology Diffusion:
Impact of the Kyoto Protocol on International Patent Applications for Renewable Energy Technologies

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May 10, 2018

Abstract

This paper examines the Kyoto Protocol's impact on the international diffusion of renewable energy technologies. Using patent application data from 133 countries from 1990 to 2013, we find that the Kyoto Protocol increased international patent applications from the countries with emission targets. When we focus on countries with more stringent targets, the effect of the Kyoto Protocol is even stronger. We find a similar effect in international patent applications to four developing countries that are large emitters of greenhouse gases (GHGs): China, India, Brazil, and Mexico. These results suggest that the Kyoto Protocol stimulated international patenting activities from countries that are committed to stringent targets for climate mitigation.

Keywords: Renewable energy; Kyoto Protocol; International patent applications

JEL Classification Numbers: O33, Q42, Q55

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1. Introduction

The Kyoto Protocol commits State Parties to reduce greenhouse gas (GHG) emissions to an average of 5% against 1990 levels. It sets binding emission reduction targets for countries under "common but differentiated responsibility and respective capabilities." Since then, many researchers have investigated the impact of the Kyoto Protocol ("Protocol") on GHG emissions. The Protocol's effect on the reduction of GHG emissions is supported by recent empirical literature. Several studies find that countries with binding emission targets under the Protocol have lower GHG emissions than they would have had in the absence of these targets (Aichele and Felbermayr, 2012; Almer and Winkler, 2017; and Grunewald and Martinez-Zarzoso, 2016).

The impact of the Protocol has also been investigated from the viewpoint of technological development. For instance, Johnstone and Haščič (2010) examine if the Protocol has an influence on patent applications for renewable energy technologies and find that a country's patent applications for wind and solar energy technologies increased after signing to the Protocol, suggesting that future expectations by firms on stricter regulations are important. Dechezleprêtre et al. (2008) focus on the transfer of GHG mitigation technologies induced by the Clean Development Mechanism (CDM), which is one of the flexible mechanisms under the

Protocol. Based on information collected from the project design documents, they found that international technology transfer takes place in less than half of CDM projects.

This study investigates whether the Protocol influenced an increase in international patent applications with respect to renewable energy technologies. Such patent applications are of interest for two reasons. First, they can be interpreted as a measure of the cross-border diffusion of climate-friendly technologies (Dechezleprêtre et al., 2013; Haščič and Johnstone, 2011). The cross-border proliferation of knowledge regarding low-carbon technologies is a key factor in climate mitigation that requires the cooperation of countries across the globe. By focusing on international patent applications, we can investigate if the Protocol affects the international transfer of climate-friendly technologies. Second, international patent applications reflect the economic value of technology by capturing changes in inventor behavior[1]. When inventors recognize a higher expected return from a patent, they will want to secure patent protection in various countries and regions (Nagaoka et al., 2010). In other words, the higher number of international patent applications represents higher economic profit from new technology.

[1] An international patent application has a strong relation to the "family size" of the patent. Haščič et al. (2010) explain international patent applications from the viewpoint of family size.

This paper makes three contributions to the existing literature on the economics of renewable energy technology. First, we investigate the effect of the Protocol on international patenting activity. There are several studies that explore technology transfer through the Protocol's Clean Development Mechanism (Dechezleprêtre et al., 2008, 2009; Haščič and Johnstone, 2011). In contrast to these project-level studies, we investigate whether the Protocol affects the total amount of international patent activity in each country. Second, we compare the pattern of international diffusion by using several treatment groups and treatment periods. By looking at the impact of the Protocol in countries with different target levels and in different periods, we can understand the breadth and strength of the Protocol's influence on technology diffusion. Third, we investigate international patent applications to four developing countries that are fast-growing emerging economies with large GHG emissions: China, India, Brazil, and Mexico. Focusing on these four countries allows us to explore the "North-to-South" technology diffusion, which has significant implications for future global GHG emissions.

The structure of this paper is organized as follows. Section 2 reviews previous literature related to the international diffusion of climate mitigation technologies. Section 3 explains the model and data used in the analysis. Section 4 presents the results of our empirical analysis.

Section 5 analyzes the impact of international patent applications on four developing countries emitting large amounts of GHGs. Finally, Section 6 concludes the study.

2. Literature Review

Several studies have examined technology transfer by using patent data (Lanjouw and Mody, 1996; Popp, 2006; Haščič and Johnstone, 2011; Dechezleprêtre et al., 2013). Lanjouw and Mody (1996) investigate the invention and diffusion of environmentally friendly technologies and describe in detail the process of international patents. They use the number of foreign patent applications as a measure of technology transfer. They found that many of the patents filed in developed countries are domestic in origin, whereas most of the patents filed in developing countries are foreign in origin. Haščič and Johnstone (2011) examine the role of the CDM under the Protocol in the transfer of wind power generation technologies. They analyze patent application data between Annex I countries and non-Annex I countries. Using patent data from over 100 countries during the period from 1988 to 2008, their estimation results suggest that the CDM has had a positive influence on the extent of transfer of wind power technologies from Annex I to non-Annex I countries. However, the estimated effects of CDM were relatively small compared with those of other factors and negative when considering the cumulative effect of CDM projects. Dechezleprêtre et al. (2013) investigate the international diffusion of patented inventions in climate-friendly technologies between 1995 and 2007. They emphasize the importance of intellectual property regimes in the international diffusion of patented knowledge. Their results suggest that the technological capacity of recipient countries reduces the transfer of foreign technologies.

This study investigates the effect of the Kyoto Protocol on international patent applications. An international patent application is defined as one in which the nationality of the first inventor does not correspond to the country in which the application is filed.[2] Some researchers regard patent citations as a measure of technology diffusion (Jaffe et al., 1993; Peri, 2005; Popp, 2006). In contrast to patent citations that reflect knowledge spillover, the number of international patent applications can be regarded as a proxy for market-driven knowledge flows (Dechezleprêtre et al., 2013). The number of cross-border patent applications does not reflect the actual transfer of technologies; instead, it provides a proxy for technology diffusion. In addition, patent systems are designed to protect new technological inventions from potential imitators (Haščič et al., 2010). Patenting might prevent a technology from being transmitted to other nations; nevertheless, technology transfer often involves patent filings in the recipient coun-

[2] An innovation is legally protected only in a country in which it is patented. Thus, some part of the technology crossing borders will show up as foreign patents and knowing the nationality of inventors allows us to identify these flows (Lanjouw and Mody, 1996).

try of new technologies. Therefore, international patenting can be regarded as a channel for technology diffusion (Eaton and Kortum, 1996).

3. Model and Data

3.1 Model

To estimate the effect of the Protocol on international patent applications, we employ a difference-in-difference (DID) estimator combined with a mix of fixed effects by running the Least Squares Dummy Variable (LSDV) model. Using the DID method, we compare the change in the number of international patent applications in countries committed to reducing GHG emissions with that in countries without such commitment. The fixed effects estimation allows us to control for time-invariant country characteristics that may be correlated with the decision to commit to emission reduction through the Protocol. The general form of the model adopted in this analysis can be written as follows:

$$\mathrm{Patent_{it}} = \beta_0 + \beta_1 Treatment\times Period_{it} + \beta_2 X_{it} + \delta_i + \gamma_t + \varepsilon_{it}, \qquad (1)$$

where i = 1, …,133 indexes countries as a cross-section unit, t = 1990, …, 2013 indexes the year as the time unit, X is a set of time-varying country characteristics, δ is a vector of country dummy, γ is the year dummy, and ε is the error term. The dependent variable (*Patent*) is the number of international patent applications for renewable energy technologies. As mentioned in Section 2, an international patent application is defined as a patent in which the nationality of the first inventor does not correspond to the country of filing. *Treatment* is the treatment indicator that takes the value one for countries that have emission targets, so-called Annex B countries, and zero otherwise. We use two treatment groups: 34 Annex B countries that have quantitative limitations under the Protocol (*Treatment 1*)[3] and 21 countries that have stronger targets among Annex B countries (*Treatment 2*)[4]. Therefore, the control group is the other 99 countries for *Treatment 1* and the other 112 countries for *Treatment 2*. *Period* represents the treatment period that takes the value of one for the year during which the Protocol is effective and zero otherwise. To compare the timing of the treatment, we adopt three treatment periods: 1997–2012 (*Period A*), 2005–2012 (*Period B*), and 2008–2012 (*Period C*). The first treatment period considers the fact that the Protocol was adopted in 1997. The second treatment period is

[3] The 34 countries are Austria, Australia, Belgium, Bulgaria, Canada, Switzerland, Czech Republic, Germany, Denmark, Estonia, Spain, Finland, France, the United Kingdom, Greece, Croatia, Hungary, Ireland, Iceland, Italy, Japan, Lithuania, Latvia, Netherlands, Norway, New Zealand, Poland, Portugal, Romania, Russian Federation, Sweden, Slovenia, Slovakia, and Ukraine.

[4] In this study, we define stronger targets as that is lower than emissions in 1990. The 21 countries are Austria, Belgium, Bulgaria, Canada, Switzerland, Czech Republic, Germany, Denmark, Estonia, United Kingdom, Croatia, Hungary, Italy, Japan, Lithuania, Latvia, The Netherlands, Poland, Portugal, Romania, Slovenia, and Slovakia. Other countries, such as Portugal, Spain, Russia, and Ukraine, have quantitative targets but they do not have to attain lower emission levels than 1990.

based on the fact that the Protocol became effective in 2005. The third treatment period is defined so as to represent the first commitment period of the Protocol.

The number of patent applications is count data and a non-negative integer-valued random variable. Count data models have been developed to deal with the number of event occurrences (Maddala, 1983; Cameron and Trivedi, 1998). Thus, we use a negative binomial model and maximum likelihood method to estimate Eq. (1). The panel of 133 countries and 24 years (1990–2013) is available, but missing observations for some countries reduce the sample size in most models estimated.

3.2 Data

Dependent variables: International application

The number of international patent applications is calculated using the Worldwide Patent Statistical Database, PATSTAT (version 2016, autumn). Following Johnstone et al. (2010), we classify patent data into each renewable energy source according to the IPC codes (see Table A1). Figure 1 shows the trends in international patent applications for wind and solar energy technologies among the 133 countries[5] from 1990 to 2013. There is a clear increase in the number of international patent applications for both types of renewable energy during the 2000s. After 2010, patent applications decrease and are back to the level of the late 2000s. The trends in domestic patent counts follow a similar pattern. Figures 2 and 3 compare the international applications for wind and solar energy technologies in Annex B countries with those in other countries. The trends of international applications in these countries are similar prior to the adoption of the Protocol in 1997, but clearly depart afterwards. Figures 4 and 5 illustrate the trends of international applications by Annex B countries that have stringent targets and those of other countries. The figures also suggest that the trend of international applications is similar before 1997, but differ after that.

[5] The 133 countries are the United Arab Emirates, Antigua and Barbados, Angola, Argentina, Austria, Australia, Azerbaijan, Barbados, Bangladesh, Belgium, Burkina Faso, Bulgaria, Bahrain, Burundi, Benin, Plurinational State of Bolivia, Brazil, Bahamas, Botswana, Belarus, Belize, Canada, Democratic Republic of the Congo, Central African Republic, Congo, Switzerland, Ivory Coast, Chile, Cameroon, China, Columbia, Costa Rica, Cape Verde, Cyprus, Czech Republic, Germany, Denmark, Dominican Republic, Algeria, Ecuador, Estonia, Egypt, Eritrea, Spain, Finland, Fiji, France, Gabon, the United Kingdom, Ghana, Guinea, Equatorial Guinea, Greece, Guatemala, Honduras, Croatia, Haiti, Hungary, Indonesia, Ireland, Israel, India, Iran, Iceland, Italy, Jamaica, Jordan, Japan, Kenya, Kiribati, Republic of Korea, Kuwait, Kazakhstan, Lao People's Democratic Republic, Lebanon, Sri Lanka, Liberia, Lesotho, Lithuania, Latvia, Morocco, Moldova, Madagascar, Mali, Mauritania, Malta, Mauritius, Malawi, Mexico, Malaysia, Mozambique, Namibia, Niger, Nigeria, the Netherlands, Norway, New Zealand, Panama, Peru, Papua New Guinea, Philippines, Pakistan, Poland, Portugal, Palau, Paraguay, Romania, Russian Federation, Saudi Arabia, Seychelles, Sweden, Singapore, Slovenia, Slovakia, Sierra Leone, Senegal, El Salvador, Syrian Arab Republic, Swaziland, Chad, Togo, Thailand, Tunisia, Tonga, Turkey, Trinidad and Tobago, Ukraine, Uganda, Uruguay, Bolivarian Republic of Venezuela, Yemen, South Africa, and Zimbabwe. The United State of America is dropped from our dataset because the country withdrew from the Kyoto Protocol in 2001.

Control variables

The estimation model includes four types of control variables: GDP per capita, FDI outflows, international application in all technological fields, and domestic patent stock. We use GDP per capita evaluated at constant US dollars in 2010 from the World Development Indicators provided[6] by the World Bank. These data capture the size of the economy in each country in each year. FDI refers to direct investment equity flows in an economy and is included in the model to control for investment in foreign countries. Data are in current US dollars. We also include the variable related to international applications in all technology fields to capture the extent of activity abroad. The data are calculated from PATSTAT. To capture the supply of inventions in each country, we include the total number of patent applications in domestic countries in the last five years.[7] A one-year lag is applied to this variable to reflect the time required to invent and apply for a patent abroad. We take logarithmic form for all continuous variables except for domestic patent stock. Tables 1–4 report descriptive statistics of the dependent and independent variables used in each estimation. We perform the *t*-test to examine if the distribution of covariates is the same between the treatment and control groups. There are statistically significant dif-

[6] http://databank.worldbank.org/data/home.aspx
[7] We also check the estimation results by using patent application flows and domestic application variables without lag and confirm that these estimation results do not differ with the main results.

ferences between the mean value of the treatment and control groups. Thus, we employ a fixed effects DID model using the LSDV approach. Furthermore, the estimation models include other variables to control these differences, particularly between developed and developing countries.

4. Empirical Results

4.1 Effect of the Kyoto Protocol on international patent applications

Table 5 reports the estimation results of models using *Treatment 1* that define Annex B countries as the treatment group. As for the treatment period dummy, specifications (1)–(3) use *Periods A–C,* respectively. All models include the country and year dummies. The coefficients of the interaction term between *Period A* and *Treatment 1* are positive and statistically significant at the 10% level for wind energy and at the 1% level for solar energy in specification (1). The results suggest that the Protocol increased international patent applications in Annex B countries after 1997. In other words, the countries that commit to emission targets of GHGs have higher numbers of international patent applications than other countries. Johnstone et al. (2010) find that the Protocol encouraged the domestic patent filings of renewable energy technologies. The results of our study suggest that the Protocol has also promoted technology diffusion through international patent applications.

The coefficient of the interaction term between *Period B* and *Treatment 1* is not statistically significant for both energy types in specification (2). The results suggest that the influence of the Protocol is not observed when we define the treatment period of the Protocol as between 2005 and 2012. The coefficient of the interaction term between *Period C* and *Treatment 1* is not statistically significant in specification (3). To summarize, the Protocol increased the number of international patent applications for renewable energy technologies in the earlier period after its adoption, but the influence is not significant in the first commitment period from 2008 to 2012.

Table 6 reports the estimation results of models using *Treatment 2* that define those among Annex B countries that have a strong target as the treatment group. In specification (4), the coefficients of the interaction term between *Period A* and *Treatment 2* are positive and statistically significant at the 1% level for wind energy and at the 5% level for solar energy. The results suggest that the Protocol increased international patent applications during 1997 and 2012. The coefficient of the interaction term between *Period B* and *Treatment 2* is positive and statistically significant at the 1 % level for wind energy in specification (5). The coefficients of the interaction terms between *Period C* and *Treatment 2* are positive and statistically significant at the 1% level for wind energy and at the 5% level for solar energy in specification (6). These results suggest that the Protocol increased international patent applications in the countries with stringent targets during the first commitment period.

4.2 Robustness check

Tables 7 and 8 present the results of the robustness check using the dataset of high-income countries.[8] As shown in Tables 1 and 2, there are statistically significant differences between the treatment and control groups. To consider the differences, we estimate models using the dataset only with high-income countries.

Table 7 reports the estimation results of models using the dataset limited to high-income countries and *Treatment 1*. The coefficient of the interaction term between *Period A* and *Treatment 1* is statistically significant at the 5% level for solar energy. We confirm that the effect of the Protocol on international patent applications for solar energy technologies is positive. On the other hand, we do not observe a statistically significant impact in specifications (8) and (9). The results suggest that the effect of the Protocol is insignificant in the latter period.

Table 8 reports the estimation results of models using *Treatment 2*. The coefficients of the interaction term between *Period A* and *Treatment 2* are positive and statistically significant at the 1% level for wind energy and at the 5% level for solar energy. The coefficient of the interaction term between *Period B* and *Treatment 2* is positive and statistically significant at the

[8] The definition of "high-income countries" is from the World Bank: https://datahelpdesk.worldbank.org/

5% level for wind energy in specification (11). Similarly, the coefficient of the interaction term between *Period C* and *Treatment 2* is positive and statistically significant at the 1% level for wind energy. The results suggest that the Protocol increased international patent applications of wind energy technologies from countries that have stronger targets under the Protocol.

5. International patent applications to developing countries

In this subsection, we explore international patent applications to four developing countries: China, India, Brazil, and Mexico. These countries are chosen as developing countries with high GHG emissions. The rapid economic growth in these countries not only increases their current carbon emissions, but is also predicted to result in higher global GHG emissions in the future. For example, China is currently the largest emitter of energy-related CO_2 emissions in the world and is projected to remain in that position through 2040 (Energy Information Administration, 2017).

Table 9 reports the estimation results. The coefficients of the interaction term between *Period A* and *Treatment 1* are positive and statistically significant at the 5% level for both of types of renewable energy technology. The results indicate that the Protocol affects international patent applications to these four developing countries. From specifications (14) and (15), we find that the coefficients of the interaction terms between *Period B* and *Treatment 1* and between *Period C* and *Treatment 1* are not statistically significant. Thus, the influence of the Protocol on international patent applications to these four developing countries is not confirmed in these periods.

Table 10 reports the estimation results using *Treatment 2*. The coefficient of the interaction term between *Period A* and *Treatment 2* is statistically significant at the 5% level for wind energy in specification (16). The coefficients of the interaction term between *Period B* and *Treatment 2* are not statistically significant in both energies in specification (17). On the other hand, the coefficients of the interaction term between *Period C* and *Treatment 2* are statistically significant at the 5% level for solar energy and at the 10% level for wind energy in specification (18). These results suggest an increase in applications to the four developing countries even in the first commitment period.

6. Conclusion

This study investigated the effect of the Kyoto Protocol on international patent applications of renewable energy technologies. Using a DID approach, we find that the Protocol increased patent applications in developed and developing countries. These findings highlight three important aspects related to the globalization of renewable energy technologies. First, inventors increased the number of international applications with respect to renewable energy after the Protocol was adopted. This effect is observed in the earlier period, particularly in the treatment period starting from 1997. Second, our results indicate that the impact of the Protocol on technology diffusion is more evident for Annex B countries with stronger GHG reduction targets. For these countries, the impact of the Protocol on the number of international patent applications remains strong even in the first commitment period. Third, the Protocol also increased international patent applications to four developing countries. Although these countries are not obliged to reduce GHG emissions under the Protocol, the estimated results suggest that firms are expecting higher demand for emission reductions in these countries.

There are two policy implications from this study. First, our results indicate the importance of international agreement on climate change for technology diffusion. The Kyoto

Protocol indirectly affects climate chage by increasing international patent applications regarding renewable energy technologies and by reducing future emissions. This effect might result in further emission reductions because international patent applications can be the first step in technology transfer (Dechezleprêtre et al., 2013) or a channel for technology diffusion (Eaton and Kortum, 1996). The second policy implication of our study is that the climate agreement might affect the expected return from renewable energy technologies. By encouraging R&D of climate-friendly technologies, international agreement can promote innovation activities that lead to patent applications. The expectation for expansion of the market for renewable energy leads to an increase in the number of international applications. The influence of introducing an international framework can be strong enough to increase international patent applications to developing countries even though the framework does not require their commitment at the current stage.

The Paris Agreement, adopted in 2015, mentioned the importance of technological development and diffusion, particularly from industrialized countries to developing countries (UN, 2016). Although the impact of this agreement on technology diffusion is yet to be confirmed, different levels of commitment by countries under the Agreement might have different impacts on technology diffusion. Further study on the effect of the climate agreement on technology diffusion is important to elaborate an international framework for mitigating climate change.

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Figure 1. International patent applications

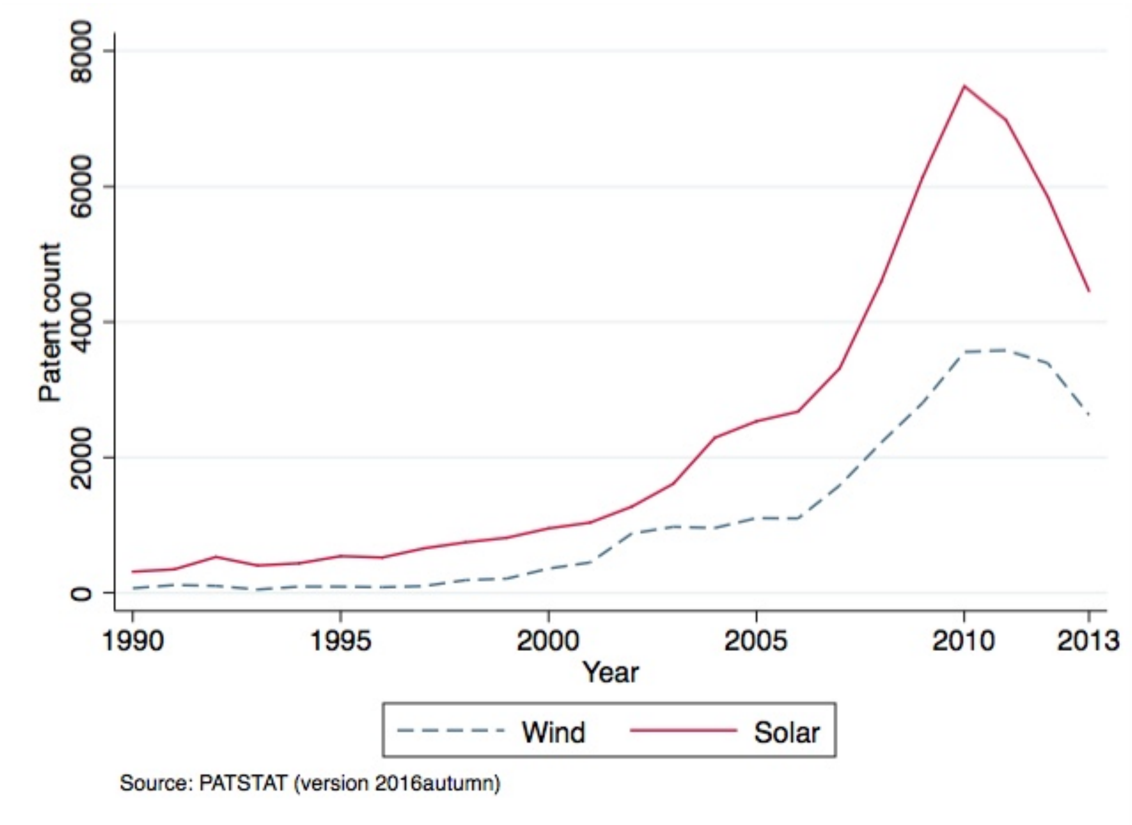

Figure 2. Annex B and non-Annex B countries: wind energy

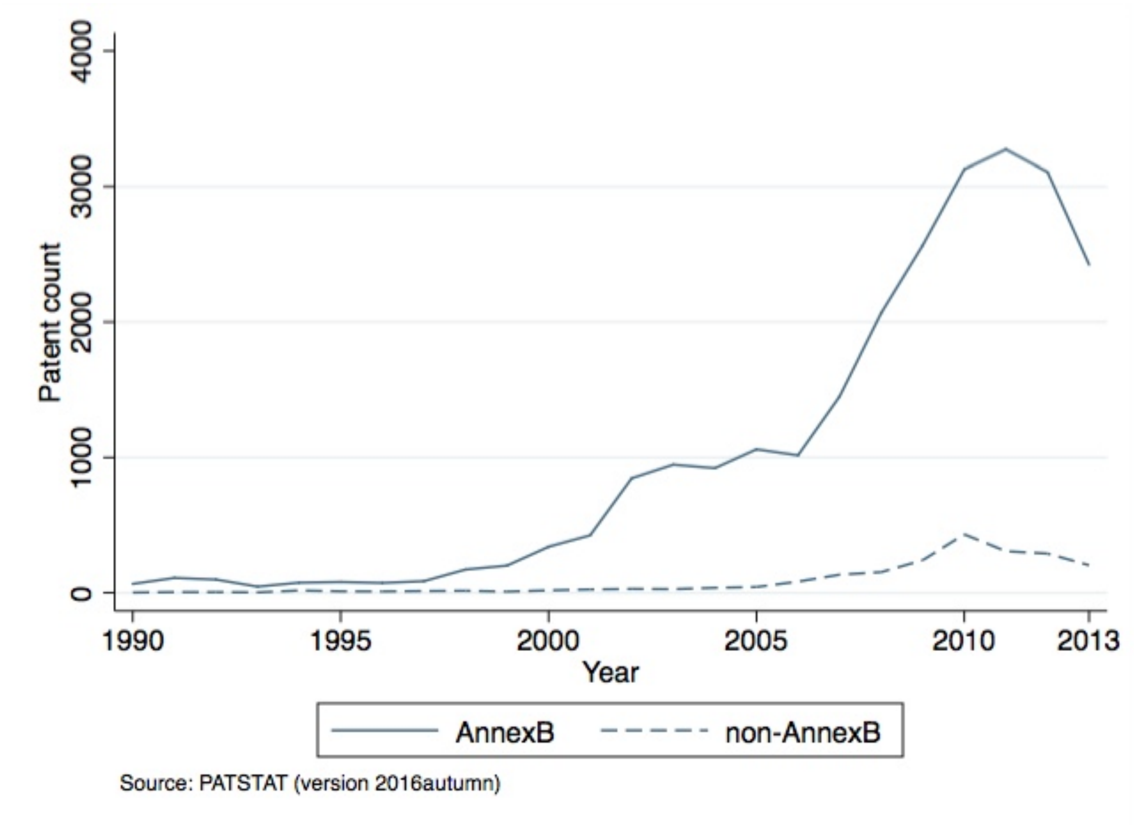

Figure 3. Annex B and non-Annex B countries: solar energy

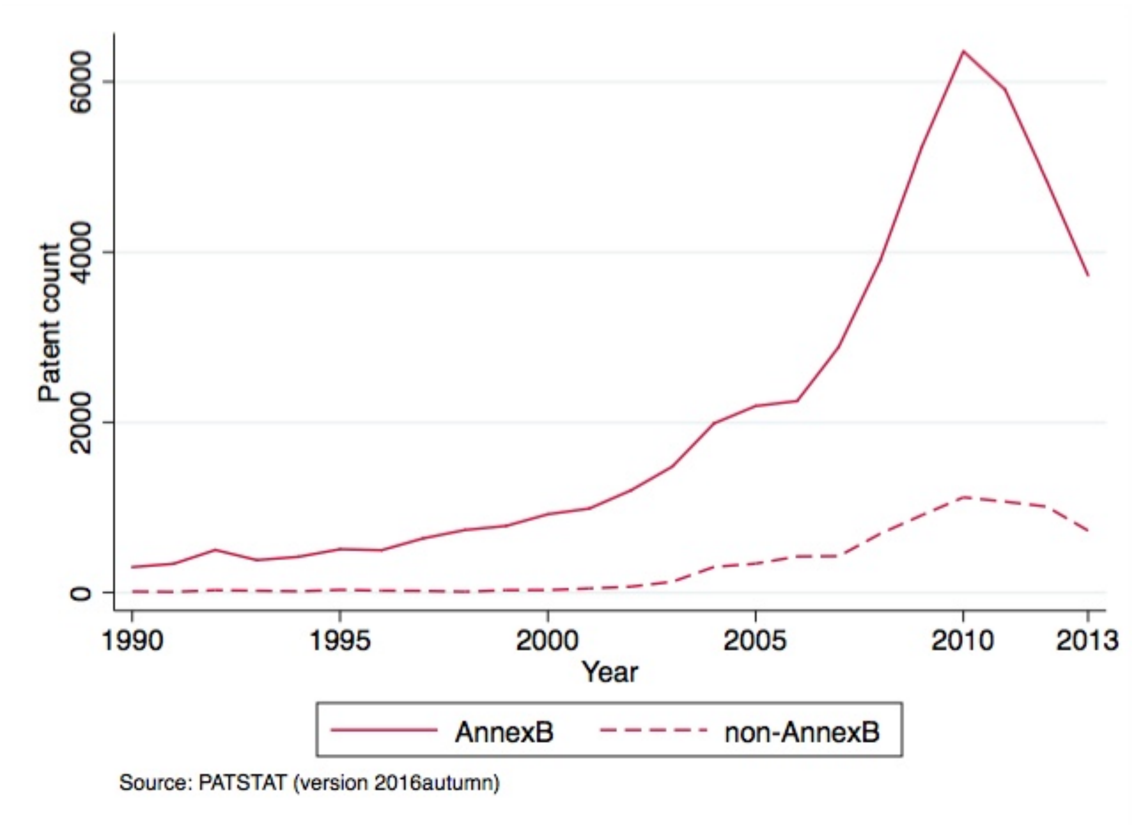

Figure 4. Strong targets in Annex B and others: wind energy

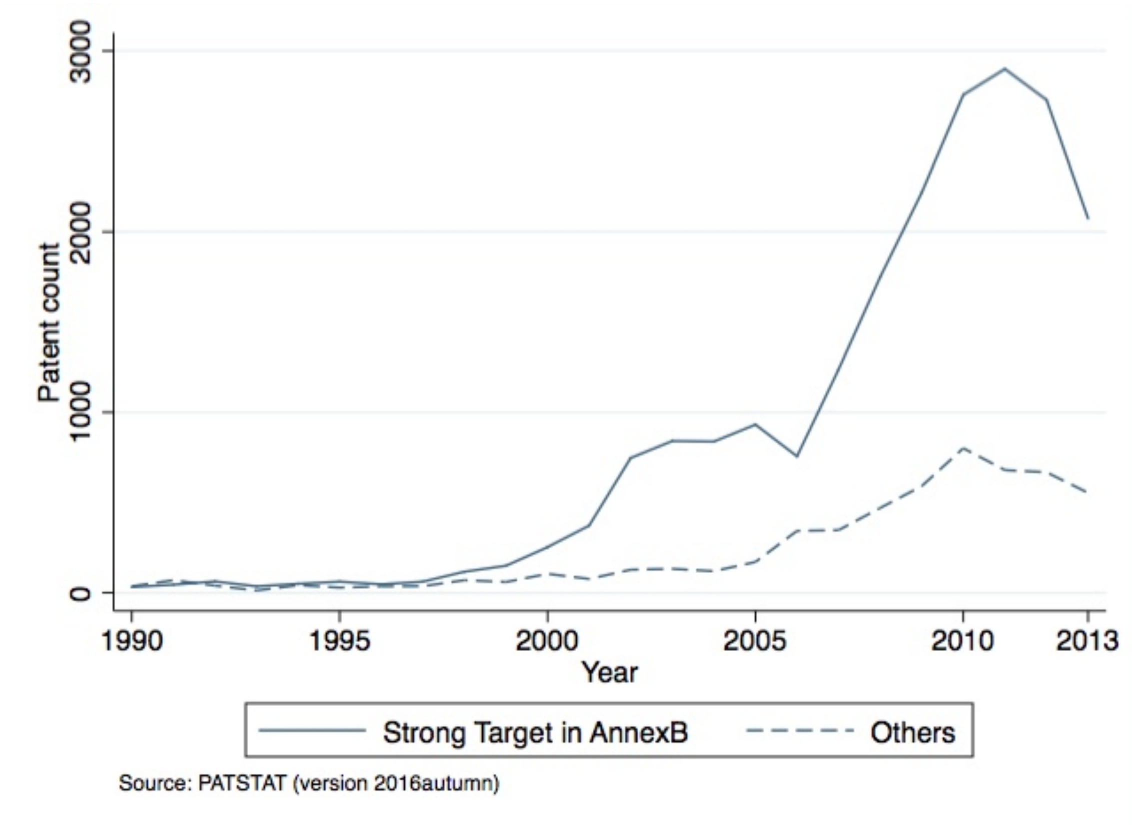

Figure 5. Strong targets in Annex B and others: solar energy

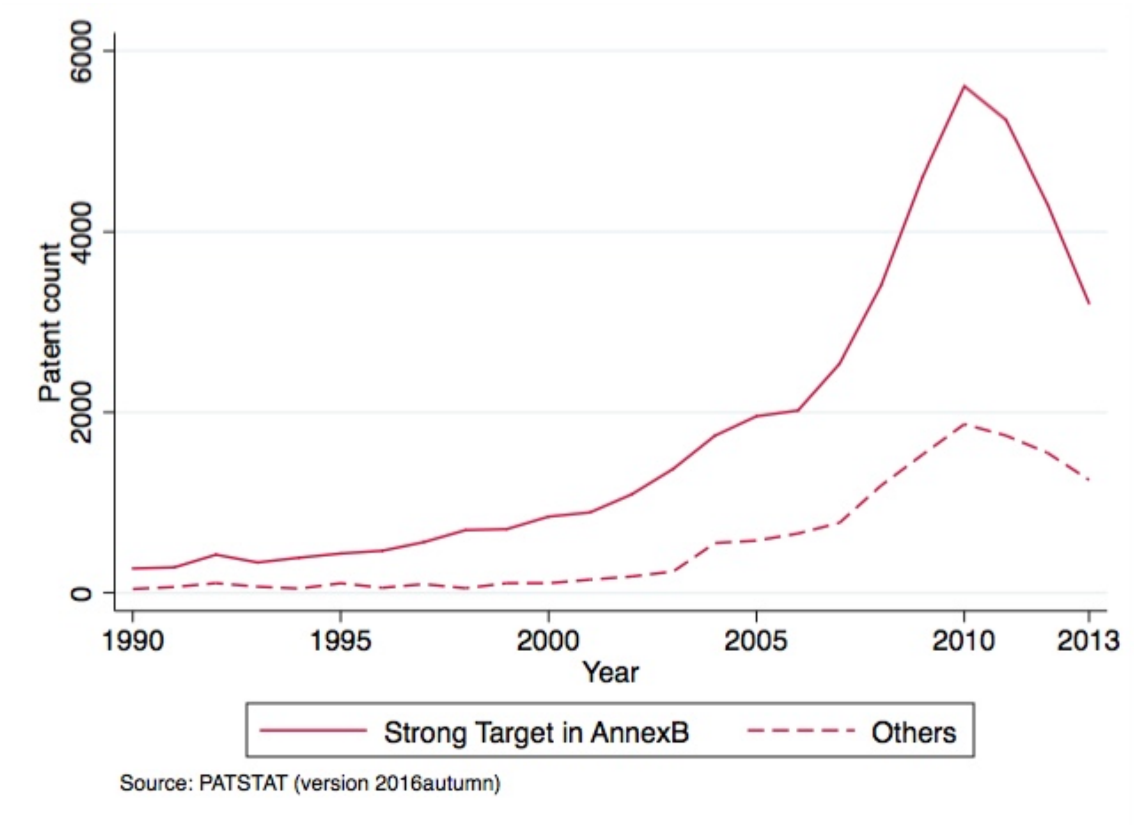

Table 1. Descriptive Statistics: Treatment 1

	Treatment1					Control					T value
	Obs	Mean	Std. Dev.	Min	Max	Obs	Mean	Std. Dev.	Min	Max	(1) and (2)
Dependent											
Wind	816	25.9559	91.5621	0	908	2,376	0.88889	6.24553	0	114	-13.2591***
Solar	816	46.0012	172.039	0	1989	2,376	3.15783	32.2143	0	683	-11.5661***
Dependent: to developing countries											
Wind	816	4.42402	17.8643	0	187	2,376	0.14646	1.12858	0	21	-11.6079***
Solar	816	6.30637	31.2249	0	471	2,376	0.40025	5.64219	0	146	-8.8129***
Interaction term											
Period A×Treatment 1	816	0.66667	0.47169	0	1	2,376	0	0	0	0	
Period B×Treatment 1	816	0.33333	0.47169	0	1	2,376	0	0	0	0	
Period C×Treatment 1	816	0.20833	0.40637	0	1	2,376	0	0	0	0	
Control											
GDP_{it} (ln)	788	10.0401	0.83975	7.43067	11.4251	2,331	7.90359	1.31385	4.75181	11.1215	-42.7872***
$FDIoutflow_{it}$ (ln)	703	14.8243	2.95605	2.30259	20.2066	1,740	10.4484	3.59873	-4.6052	18.1056	-28.5787***
$Interappln_{it}$ (ln)	816	7.1528	2.34649	1.60944	12.0442	1,827	2.87012	2.27904	0	10.8294	-44.2223***
Domestic stock of $wind_{it-1}$	816	40.0858	123.632	0	1499	2,376	7.30387	91.7978	0	2563	-8.0079***
Domestic stock of $solar_{it-1}$	816	73.348	268.385	0	3200	2,376	5.8771	76.3108	0	1626	-11.0274***

Table 2. Descriptive Statistics: Treatment 2

	Treatment2					Control					T value
	Obs	Mean	Std. Dev.	Min	Max	Obs	Mean	Std. Dev.	Min	Max	(1) and (2)
Dependent											
Wind	504	35.0615	113.982	0	908	2,688	2.09115	10.7527	0	180	-14.6626***
Solar	504	63.3452	214.182	0	1989	2,688	4.87872	34.3805	0	683	-13.278***
Dependent: to developing countries											
Wind	504	6.13691	22.2345	0	187	2,688	0.3218	2.04259	0	40	-13.2729***
Solar	504	8.78373	39.2128	0	471	2,688	0.62128	5.77788	0	146	-10.2229***
Interaction term											
Period A×Treatment 2	504	0.66667	0.47187	0	1	2,688	0	0	0	0	
Period B×Treatment 2	504	0.33333	0.47187	0	1	2,688	0	0	0	0	
Period C×Treatment 2	504	0.20833	0.40652	0	1	2,688	0	0	0	0	
Control											
GDP_{it} (ln)	476	9.95231	0.81191	8.18392	11.2309	2,643	8.17162	1.46537	4.75181	11.4251	-25.8061***
$FDIoutflow_{it}$ (ln)	436	14.6222	3.26974	2.30259	20.2066	2,007	11.0744	3.80774	-4.6052	18.9721	-18.0618***
$Interappln_{it}$ (ln)	504	7.06961	2.6704	1.60944	12.0442	2,139	3.5144	2.69905	0	10.8294	-26.6565***
Domestic stock of $wind_{it-1}$	504	47.6944	150.18	0	1499	2,688	9.68229	88.7529	0	2563	-7.7572***
Domestic stock of $solar_{it-1}$	504	96.9147	328.799	0	3200	2,688	9.28981	81.0762	0	1626	-12.0124***

Table 3. Descriptive Statistics: Treatment 1 and High-income Countries

	Treatment1					Control					T value
	Obs	Mean	Std. Dev.	Min	Max	Obs	Mean	Std. Dev.	Min	Max	(1) and (2)
Dependent											
Wind	696	30.0172	98.5511	0	908	408	2.25735	9.12485	0	80	-5.6744***
Solar	696	53.523	185.251	0	1989	408	14.375	74.6255	0	683	-4.0784***
Dependent: to developing countries											
Wind	696	5.1523	19.2485	0	187	408	0.44608	2.11047	0	20	-4.9204***
Solar	696	7.37069	33.6984	0	471	408	2.13971	13.4722	0	146	-2.9977**
Interaction term											
Period A×Treatment 1	696	0.66667	0.47174	0	1	408	0	0	0	0	
Period B×Treatment 1	696	0.33333	0.47174	0	1	408	0	0	0	0	
Period C×Treatment 1	696	0.20833	0.40641	0	1	408	0	0	0	0	
Control											
GDP_{it} (ln)	673	10.2769	0.62203	8.54344	11.4251	402	9.7879	0.5558	8.69077	11.1215	-12.9685***
$FDIoutflow_{it}$ (ln)	612	15.2415	2.67292	4.82831	20.2066	333	11.9791	3.96346	-4.6052	17.7685	-15.0303***
$Interappln_{it}$ (ln)	696	7.46129	2.32595	1.60944	12.0442	369	3.86898	2.65498	0	10.8294	-22.8171***
Domestic stock of $wind_{it-1}$	696	40.0474	130.209	0	1499	408	23.0515	191.025	0	2563	-1.7533*
Domestic stock of $solar_{it-1}$	696	81.3879	289.235	0	3200	408	0.70343	2.60462	0	18	-5.6335***

Table 4. Descriptive Statistics: Treatment 2 and High-income Countries

	Treatment2					Control					T value
	Obs	Mean	Std. Dev.	Min	Max	Obs	Mean	Std. Dev.	Min	Max	(1) and (2)
Dependent											
Wind	432	40.8565	122.174	0	908	672	6.19494	18.6319	0	180	-7.2267***
Solar	432	73.7662	229.727	0	1989	672	16.7411	65.8633	0	683	-6.0604***
Dependent: to developing countries											
Wind	432	7.15509	23.868	0	187	672	1.00744	3.77081	0	40	-6.5525***
Solar	432	10.2338	42.1868	0	471	672	2.35417	11.3705	0	146	-4.5905***
Interaction term											
Period A×Treatment 2	432	0.66667	0.47195	0	1	672	0	0	0	0	
Period B×Treatment 2	432	0.33333	0.47195	0	1	672	0	0	0	0	
Period C×Treatment 2	432	0.20833	0.40659	0	1	672	0	0	0	0	
Control											
GDP_{it} (ln)	409	10.1372	0.70208	8.54344	11.2309	666	10.0675	0.60289	8.69077	11.4251	-1.729*
$FDIoutflow_{it}$ (ln)	383	15.1575	2.96497	4.82831	20.2066	562	13.3657	3.72553	-4.6052	18.9721	-7.8661***
$Interappln_{it}$ (ln)	432	7.52213	2.60036	1.60944	12.0442	633	5.32567	2.89937	0	10.8294	-12.6512***
Domestic stock of $wind_{it-1}$	432	53.5857	161.402	0	1499	672	21.0253	150.521	0	2563	-3.4093***
Domestic stock of $solar_{it-1}$	432	110.843	353.241	0	3200	672	13.4658	72.6916	0	1072	-6.9233***

Table 5. Results of Treatment 1: Annex B Countries

	KyotoA(1997-2012)		KyotoB(2005-2012)		KyotoC(2008-2012)	
	(1)		(2)		(3)	
	wind	solar	wind	solar	wind	solar
Period A×Treatment 1	0.472*	0.527**				
	(0.263)	(0.207)				
Period B×Treatment 1			0.318	0.114		
			(0.197)	(0.164)		
Period C×Treatment 1					0.191	0.134
					(0.199)	(0.159)
GDP(ln)	-0.696	0.385	-0.621	0.429	-0.639	0.444
	(0.585)	(0.374)	(0.581)	(0.381)	(0.587)	(0.385)
FDIoutflow(ln)	-0.100**	-0.079*	-0.093**	-0.074	-0.091**	-0.073
	(0.045)	(0.046)	(0.045)	(0.048)	(0.045)	(0.048)
Interappln(ln)	0.912***	1.114***	0.916***	1.073***	0.884***	1.066***
	(0.155)	(0.113)	(0.157)	(0.121)	(0.152)	(0.117)
Domestic stock	0.000	-0.000	0.000	-0.000	0.000	-0.000
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
_cons	3.331	-8.909***	2.456	-8.793**	3.041	-8.892**
	(4.957)	(3.366)	(5.018)	(3.484)	(5.087)	(3.552)
N	2035	2035	2035	2035	2035	2035
AIC	5410.044	6246.511	5410.896	6250.141	5412.077	6250.084
BIC	6275.255	7111.721	6276.107	7115.351	6277.288	7115.295
log_likelihood	-2551.022	-2969.255	-2551.448	-2971.070	-2552.038	-2971.042

Note: Standard errors are between parentheses. *, **, and *** indicate statistical significance at the $p < 0.1$, $p < 0.05$, and $p < 0.01$ levels, respectively.

Table 6. Results of Treatment 2: Annex B Countries with Stronger Targets

	KyotoA(1997-2012)		KyotoB(2005-2012)		KyotoC(2008-2012)	
	(4)		(5)		(6)	
	wind	solar	wind	solar	wind	solar
Period A×Treatment 2	0.653***	0.345**				
	(0.230)	(0.165)				
Period B×Treatment 2			0.444***	0.118		
			(0.163)	(0.128)		
Period C×Treatment 2					0.484***	0.308**
					(0.170)	(0.137)
GDP(ln)	-0.617	0.444	-0.555	0.436	-0.579	0.461
	(0.582)	(0.380)	(0.586)	(0.385)	(0.582)	(0.385)
FDIoutflow(ln)	-0.103**	-0.078	-0.098**	-0.075	-0.093**	-0.074
	(0.046)	(0.047)	(0.045)	(0.048)	(0.045)	(0.048)
Interappln(ln)	0.901***	1.074***	0.900***	1.064***	0.889***	1.071***
	(0.153)	(0.114)	(0.151)	(0.117)	(0.151)	(0.116)
Domestic stock	0.000	-0.000	0.000	-0.000	0.000	-0.000
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
_cons	2.507	-9.048***	1.962	-8.743**	2.283	-9.108***
	(4.973)	(3.446)	(5.056)	(3.511)	(4.995)	(3.516)
N	2035	2035	2035	2035	2035	2035
AIC	5407.335	6248.587	5408.985	6250.108	5409.012	6248.858
BIC	6272.546	7113.797	6274.195	7115.318	6274.223	7114.069
log_likelihood	-2549.668	-2970.293	-2550.492	-2971.054	-2550.506	-2970.429

Note: Standard errors are between parentheses. *, **, and *** indicate statistical significance at the $p < 0.1$, $p < 0.05$, and $p < 0.01$ levels, respectively.

Table 7. Robustness Checks: High-income Countries and Treatment 1

	KyotoA(1997-2012)		KyotoB(2005-2012)		KyotoC(2008-2012)	
	(7)		(8)		(9)	
	wind	solar	wind	solar	wind	solar
Period A×Treatmen t1	0.322	0.579**				
	(0.333)	(0.272)				
Period B×Treatment 1			0.055	-0.239		
			(0.253)	(0.219)		
Period C×Treatment 1					-0.164	-0.523**
					(0.253)	(0.224)
GDP(ln)	0.803	0.715	0.786	0.557	0.794	0.568
	(0.797)	(0.505)	(0.796)	(0.522)	(0.805)	(0.534)
FDIoutflow(ln)	-0.207***	-0.129***	-0.200***	-0.109***	-0.201***	-0.114***
	(0.061)	(0.040)	(0.061)	(0.040)	(0.062)	(0.041)
Interappln(ln)	0.643***	1.317***	0.606***	1.142***	0.573***	1.121***
	(0.188)	(0.155)	(0.193)	(0.159)	(0.189)	(0.151)
Domestic stock	0.000	-0.000	0.000	-0.000	0.000	-0.000
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
_cons	-7.603	-13.664***	-7.059	-10.074*	-6.690	-9.836*
	(7.974)	(5.209)	(8.028)	(5.350)	(8.080)	(5.413)
N	892	892	892	892	892	892
AIC	3965.981	4704.846	3966.458	4706.266	3966.307	4704.915
BIC	4311.110	5049.975	4311.588	5051.395	4311.436	5050.045
log_likelihood	-1910.990	-2280.423	-1911.229	-2281.133	-1911.153	-2280.458

Note: Standard errors are between parentheses. *, **, and *** indicate statistical significance at the $p < 0.1$, $p < 0.05$, and $p < 0.01$ levels, respectively.

Table 8. Robustness Checks: High-income Countries and Treatment 2

	KyotoA(1997-2012) (10)		KyotoB(2005-2012) (11)		KyotoC(2008-2012) (12)	
	wind	solar	wind	solar	wind	solar
Period A×Treatment 2	0.696***	0.343**				
	(0.251)	(0.170)				
Period B×Treatment 2			0.435**	-0.032		
			(0.172)	(0.135)		
Period C×Treatment 2					0.478***	0.012
					(0.182)	(0.143)
GDP(ln)	1.019	0.746	0.846	0.600	0.762	0.603
	(0.798)	(0.511)	(0.799)	(0.519)	(0.790)	(0.519)
FDIoutflow(ln)	-0.215***	-0.122***	-0.212***	-0.110***	-0.205***	-0.112***
	(0.061)	(0.041)	(0.061)	(0.041)	(0.061)	(0.041)
Interappln(ln)	0.698***	1.258***	0.674***	1.190***	0.648***	1.198***
	(0.185)	(0.145)	(0.187)	(0.150)	(0.186)	(0.148)
Domestic stock	0.000	-0.000	0.000	-0.000	0.000	-0.000
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
_cons	-10.632	-13.424**	-8.393	-11.098**	-7.283	-11.213**
	(8.055)	(5.273)	(8.090)	(5.298)	(7.936)	(5.289)
N	892	892	892	892	892	892
AIC	3962.037	4705.431	3964.001	4706.651	3964.047	4706.664
BIC	4307.166	5050.561	4309.131	5051.781	4309.176	5051.793
log_likelihood	-1909.018	-2280.716	-1910.001	-2281.326	-1910.023	-2281.332

Note: Standard errors are between parentheses. *, **, and *** indicate statistical significance at the $p < 0.1$, $p < 0.05$, and $p < 0.01$ levels, respectively.

Table 9. International Applications in Developing Countries: Treatment 1

	KyotoA(1997-2012)		KyotoB(2005-2012)		KyotoC(2008-2012)	
	(13)		(14)		(15)	
	wind	solar	wind	solar	wind	solar
Period A×Treatment 1	0.771**	0.845**				
	(0.351)	(0.357)				
Period B×Treatment 1			0.428	0.433		
			(0.306)	(0.293)		
Period C×Treatment 1					0.169	0.391
					(0.316)	(0.266)
GDP(ln)	-2.050	-0.017	-1.902	0.439	-1.954	0.600
	(1.626)	(0.941)	(1.647)	(0.880)	(1.765)	(0.881)
FDIoutflow(ln)	0.070	-0.111*	0.089	-0.109*	0.091	-0.103*
	(0.107)	(0.063)	(0.107)	(0.061)	(0.107)	(0.062)
Interappln(ln)	1.008***	0.920***	1.054***	0.850***	1.009***	0.796***
	(0.369)	(0.280)	(0.358)	(0.272)	(0.372)	(0.266)
Domestic stock	0.000	0.000	0.000	0.000	0.000	0.000
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
_cons	12.096	-3.533	9.764	-7.493	10.901	-8.637
	(12.849)	(7.940)	(13.543)	(7.631)	(14.665)	(7.790)
N	2035	2035	2035	2035	2035	2035
AIC	2476.794	2795.828	2478.091	2798.090	2479.269	2798.374
BIC	3342.005	3661.038	3343.302	3663.301	3344.479	3663.584
log_likelihood	-1084.397	-1243.914	-1085.046	-1245.045	-1085.634	-1245.187

Note: Standard errors are between parentheses. *, **, and *** indicate statistical significance at the $p < 0.1$, $p < 0.05$, and $p < 0.01$ levels, respectively.

Table 10. International Applications in Developing Countries: Treatment 2

	KyotoA(1997-2012) (16)		KyotoB(2005-2012) (17)		KyotoC(2008-2012) (18)	
	wind	solar	wind	solar	wind	solar
Period A×Treatmen t2	0.653**	0.277				
	(0.330)	(0.266)				
Period B×Treatment 2			0.352	0.271		
			(0.249)	(0.200)		
Period C×Treatment 2					0.430*	0.479**
					(0.228)	(0.193)
GDP(ln)	-2.005	0.398	-1.846	0.482	-1.804	0.570
	(1.646)	(0.888)	(1.692)	(0.882)	(1.687)	(0.883)
FDIoutflow(ln)	0.087	-0.111*	0.084	-0.115*	0.091	-0.112*
	(0.109)	(0.062)	(0.108)	(0.061)	(0.107)	(0.062)
Interappln(ln)	0.992***	0.753***	1.015***	0.776***	1.008***	0.793***
	(0.374)	(0.259)	(0.368)	(0.258)	(0.370)	(0.260)
Domestic stock	0.000	0.000	0.000	0.000	0.000	0.000
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
_cons	11.396	-5.923	9.704	-6.915	9.213	-8.117
	(13.036)	(7.696)	(13.798)	(7.739)	(13.810)	(7.770)
N	2035	2035	2035	2035	2035	2035
AIC	2477.214	2798.905	2478.299	2798.713	2477.873	2797.365
BIC	3342.425	3664.116	3343.509	3663.924	3343.083	3662.576
log_likelihood	-1084.607	-1245.452	-1085.149	-1245.357	-1084.936	-1244.683

Note: Standard errors are between parentheses. *, **, and *** indicate statistical significance at the $p < 0.1$, $p < 0.05$, and $p < 0.01$ levels, respectively.

Appendix

Table A1. IPC codes

IPC code	Explanation
Wind	
F03D 1	Wind motors with rotation axis substantially in wind direction
F03D 3	Wind motors with rotation axis substantially at right angle to wind direction
F03D 5	Other wind motors
F03D 7	Controlling wind motors
F03D 9	Adaptations of wind motors for special use
F03D 11	Details, component parts, or accessories not provided for in, or of interest apart from, the other groups of this subclass
Solar	
F03G 6	Devices for producing mechanical power from solar energy
F24J 2	Use of solar heat, e.g. solar heat collectors
H01L 27/142	Devices consisting of a plurality of semiconductor components sensitive to infra-red radiation, light—specially adapted for the conversion of the energy of such radiation into electrical energy
H01L 31/04-078	Semiconductor devices sensitive to infra-red radiation, light—adapted as conversion devices
H02N 6	Generators in which light radiation is directly converted into electrical energy
E04D 13/18	Aspects of roofing for energy collecting devices—e.g. incl. solar panels

Source: Johnstone et al. (2010)