

**International environment agreements and emissions reduction:
new insights from a staggered difference-in-difference analysis**

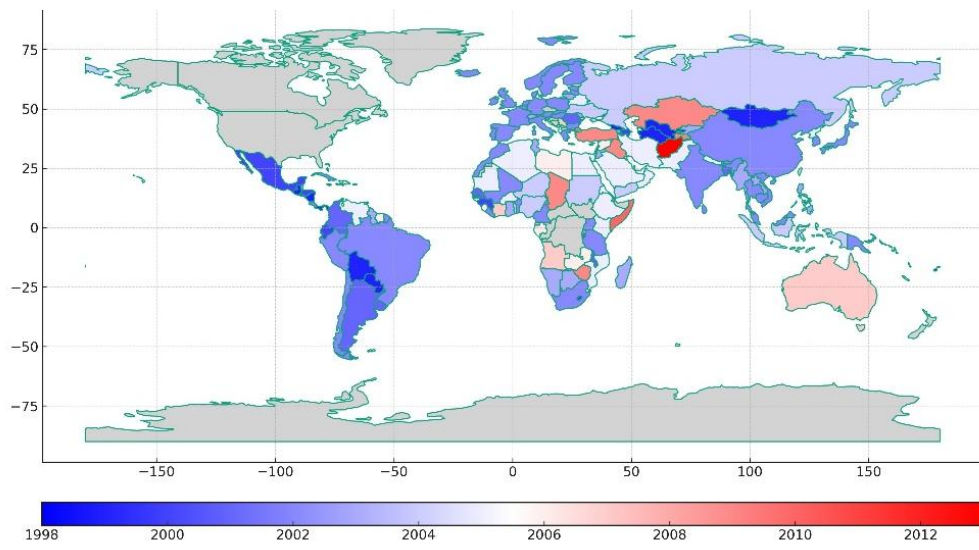
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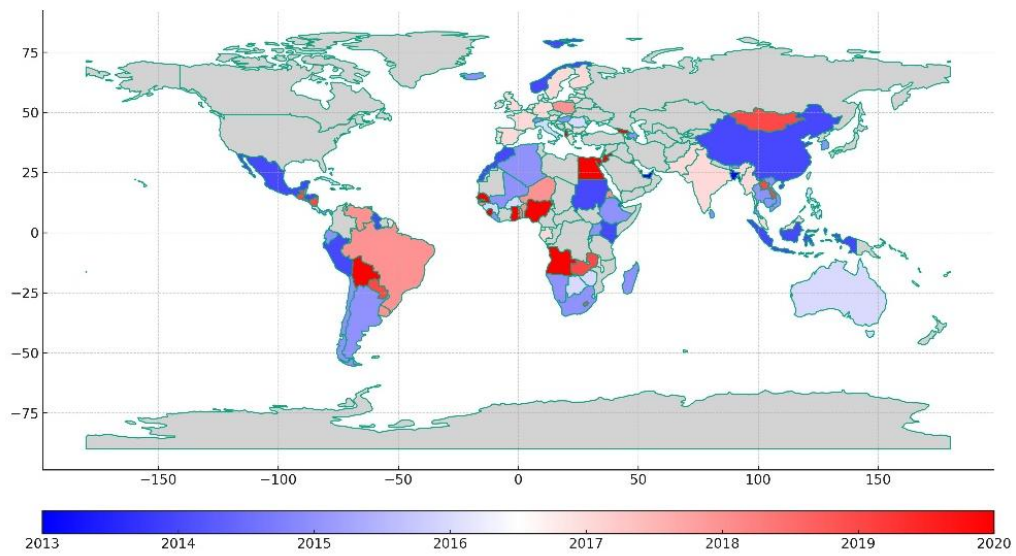
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ONLINE APPENDIX

Appendix A



(a) Acceptance year for the KP (1998–2012).



(b) Acceptance year for the DA (2013–2020).

Figure A1. The KP and DA acceptance timeframes.

Table A1. Summary statistics

Variable	N	Mean	Standard Deviation	Min	Max
<i>CO2</i>	5,492	0.55	0.58	0.00	5.17
<i>CO2a</i>	5,796	130,472.96	590,545.50	0.00	10,944,686.20
<i>CO2b</i>	5,796	4.15	5.33	0.00	47.66
<i>POP</i>	5,859	35,024,502.81	31,938,537.47	9,182.00	1,411,100,000.00
<i>GDP</i>	5,528	11,741.28	18,870.28	189.28	191,194.47

Notes: *CO2* measures CO₂ emissions in kg per 2015 US\$ of GDP, *CO2a* measures CO₂ emissions in kiloton, *CO2b* measures CO₂ emissions in metric tons per capita, *POP* is natural logarithm of total population, and *GPD* denotes GDP per capita (constant 2015 US\$). *N* stands for the number of country-year observations.

Table A2. Parallel trend tests**Part A.** The KP and DA as independent events

Dependent variable	Kyoto Protocol (KP)		Doha Amendment (DA)	
	-2 years	-3 years	-2 years	-3 years
<i>CO2</i>	0.373	0.231	0.417	0.139
<i>CO2a</i>	0.224	0.156	0.173	0.009*
<i>CO2b</i>	0.375	0.234	0.452	0.184

Part B. The KP and DA as staggered events

Dependent variable	Kyoto Protocol (KP)		Doha Amendment (DA)	
	-2 years	-3 years	-2 years	-3 years
<i>CO2</i>	0.309	0.472	0.819	0.931
<i>CO2a</i>	0.271	0.427	0.656	0.788
<i>CO2b</i>	0.290	0.460	0.628	0.768

Notes: This table presents the p -values of the parallel trend tests for the three dependent variables at 2 and 3 years before the event dates across the KP and DA members. *CO2* measures CO₂ emissions in kg per 2015 US\$ of GDP (in logarithm), *CO2a* measures CO₂ emissions in kiloton (in logarithm), *CO2b* measures CO₂ emissions in metric tons per capita (in logarithm). * denotes that the parallel assumption is violated so DID is not appropriate.

Table A3. Anticipation effects

Dependent variable	Kyoto Protocol (KP)		Doha Amendment (DA)	
	+2 years	+3 years	+2 years	+3 years
$\tau_{w(CO2)}$	0.009 (0.775)	0.004 (0.905)	-0.001 (0.999)	-0.005 (0.892)
$\tau_{w(CO2a)}$	0.009 (0.774)	0.008 (0.841)	0.002 (0.94)	-0.001 (0.990)
$\tau_{w(CO2b)}$	0.015 (0.621)	0.014 (0.707)	0.006 (0.846)	0.003 (0.925)

Notes: This table presents the anticipation effects of the three dependent variables at 2 and 3 years after the event dates across the KP and DA members. τ_w denotes the imputation-based treatment effects (see Equation (2) and the relevant discussions). *CO2* measures CO₂ emissions in kg per 2015 US\$ of GDP (in logarithm), *CO2a* measures CO₂ emissions in kiloton (in logarithm), *CO2b* measures CO₂ emissions in metric tons per capita (in logarithm). *p*-values are presented inside the brackets.

Table A4. Time-sensitive effects of the KP on CO₂ emissions reduction

	+1 year	+2 years	+3 years
$\tau_w(CO2)$	-0.051*	-0.073**	-0.096***
<i>p</i> -value	(0.053)	(0.013)	(0.004)
Observations	2,561	2,739	2,917
$\tau_w(CO2a)$	-0.049*	-0.072**	-0.094**
<i>p</i> -value	(0.083)	(0.027)	(0.011)
Observations	2,561	2,739	2,917
$\tau_w(CO2b)$	-0.043	-0.065**	-0.085**
<i>p</i> -value	(0.104)	(0.031)	(0.012)
Observations	2,561	2,739	2,917

Notes: The table presents the time-sensitive effects of Kyoto Protocol on CO₂ emission reduction. τ_w denotes the imputation-based treatment effects (see Equation (2) and the relevant discussions). *CO2* measures CO₂ emissions in kg per 2015 US\$ of GDP (in logarithm), *CO2a* measures CO₂ emissions in kiloton (in logarithm), *CO2b* measures CO₂ emissions in metric tons per capita (in logarithm). *p*-values are presented inside the brackets. *, **, and *** denote the statistical significance at the 10%, 5%, and 1% levels, respectively.

Appendix B. The average group-time treatment effect (AGGTT) robustness test

The measure of the average treatment effect on the treated for a particular group i at the point of treatment, specified at time t ($ATT(i, t)$), is of interest. Factoring in all the sophisticated enhancements of the doubly robust estimators, this is estimated when $t \geq i$, as follows:

$$ATT(i, t) = [EY(i)_t - EY(NT)_t] - [EY(i)_{i-1} - EY(NT)_{i-1}]. \quad (A1)$$

Here, NT is an abbreviation for "never treated", which, in most circumstances, can serve effectively as a favorable control group. $EY(c)_t$ is the expected value of the outcome at time t , for group c . The first parenthesis evaluates the disparities in outcomes at a specific time t , while the subsequent parenthesis computes the difference in outcome at time $i - 1$, the period before the implementation of the treatment.

After that, we aggregate the average group-time treatment effect (AGGTT) by the formula:

$$AGGTT = \frac{\sum w_{i,t} \times ATT(i, t)}{\sum w_{i,t}} \quad (A2)$$

where $w_{i,t}$ accounts for weight of how much information was employed in $ATT(i, t)$ estimation process. Estimators exhibiting larger magnitudes and greater precision ought to be allocated more weight. Conversely, those derived from a relatively small number of observations should be assigned less weight (Callaway and Li, 2023).

In the case of AGGTT, the stabilized inverse probability weight has been used due to its ability to perform well with unbalanced data from its capability to adjust for treatment selection bias based on observed characteristics, creating a pseudo-population where treatment assignment appears random. While the imputation estimator addresses the issue of negative weights by imputing expected values based on historical data, the AGGTT approach employs an alternative strategy. This method utilizes a comparison group composed of units that have not undergone

treatment during the panel's timeframe. Alternatively, the approach might involve a pool of units that have not yet received treatment by the time of the intervention. This offers a robust comparison group to examine the effects of treatment. Even though the AGGTT approach does not consider observations of nations that have undergone treatment yet could still serve as a control group in the imputation estimator method, it nevertheless remains capable of generating an unbiased and consistent estimation of each group's unique group-time ATT.

References

Callaway B and Li T (2023) Policy evaluation during a pandemic. *Journal of Econometrics* **236**, 105454.

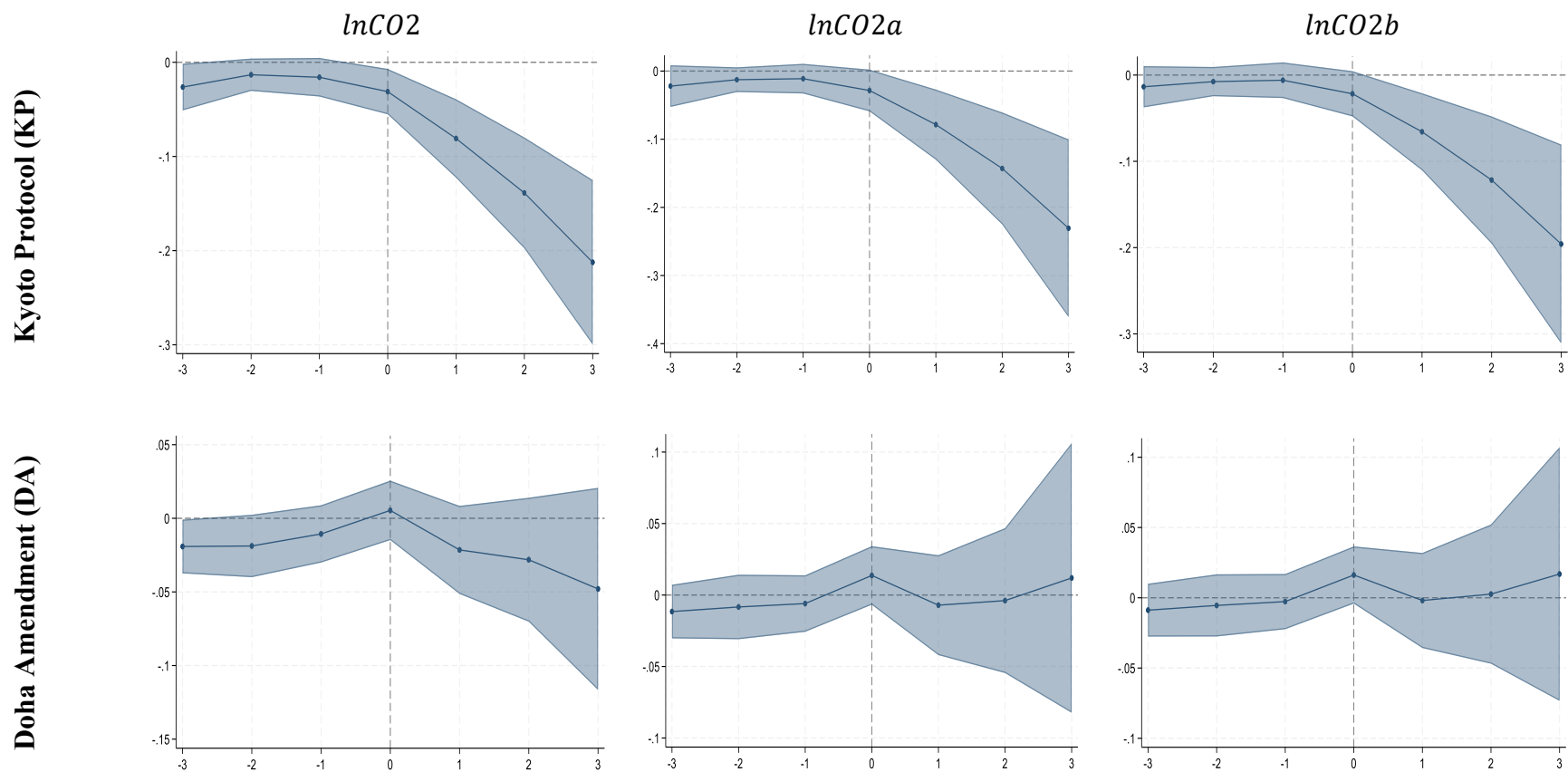


Figure A2. The impacts of KP and DA on CO₂ emissions reduction (AGGTT approach)

Notes: The vertical axes of the charts report the Average causal effect while the horizontal axes report the periods relative to the event (i.e., Event = Period 0). The dots indicate the difference regarding the CO₂ emissions between treatment and control groups (nations that have ratified the KP or DA and those that are yet to accept it accordingly). The dots before the event date show the trend of differences during pre-treatment and the dots after the event dates show the post-treatment periods regarding the KP and DA, respectively.

Table A5. The AGGTT analysis for CO₂ emissions reduction**Part A.** For the Kyoto Protocol (KP)

	+1 year	+2 years	+3 years
<i>AGGTT(CO2)</i>	-0.080***	-0.139***	-0.212***
<i>p</i> -value	(0.000)	(0.000)	(0.000)
<i>AGGTT(CO2a)</i>	-0.078***	-0.142***	-0.231***
<i>p</i> -value	(0.003)	(0.001)	(0.001)
<i>AGGTT(CO2b)</i>	-0.065***	-0.122***	-0.195***
<i>p</i> -value	(0.004)	(0.001)	(0.001)

Part B. For the Doha Amendment (DA)

	+1 year	+2 years	+3 years
<i>AGGTT(CO2)</i>	-0.021	-0.028	-0.047
<i>p</i> -value	(0.159)	(0.190)	(0.171)
<i>AGGTT(CO2a)</i>	-0.007	-0.003	0.012
<i>p</i> -value	(0.691)	(0.880)	(0.804)
<i>AGGTT(CO2b)</i>	-0.002	0.002	0.017
<i>p</i> -value	(0.911)	(0.918)	(0.714)

Notes: *CO2* measures CO₂ emissions in kg per 2015 US\$ of GDP (in logarithm), *CO2a* measures CO₂ emissions in kiloton (in logarithm), *CO2b* measures CO₂ emissions in metric tons per capita (in logarithm). *p*-values are presented inside the brackets. *, **, and *** denote the statistical significance at the 10%, 5%, and 1% levels, respectively.