Impact of Kyoto Protocol on Green Growth

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February, 2022
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Abstract

Some recent studies provide causal evidence that suggest that the Kyoto protocol (KP) led to a reduction in GHG emissions. What are the channels through which the KP led to GHG emissions reduction; increased renewable energy (RE) consumption, energy efficiency (EE) or both? In this paper, I examined the causal impact of the KP on RE and EE by combining the Entropy balancing method with a differences-in-differences technique to deal with endogeneity issues. This allowed me to compare countries legally bound by the KP to a comparable control group of countries not legally bound by the KP. The results showed that the KP led to an increase in RE but not significant impact on EE.
Keywords: Kyoto Protocol, Renewable Energy, Energy Efficiency
JEL classification codes:

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1 Introduction

Climate change is considered one of the greatest threats to the economic and social resilience of many countries. There has been substantial increase in temperatures and extreme weather events globally in the past half century. This is mainly due to the sustained increase in well-mixed greenhouse gas (GHG) concentrations caused by human activities (IPCC, 2021). In view of this, numerous international agreements and policies have been enacted with the goal to limit GHG emissions. One of which is the Kyoto protocol (KP). The KP placed binding on the so-called Annex-B (industrialized) countries to reduce their emissions to an average of 5% below 1990 levels over the first commitment period[1] (United Nations, 1998).

At the heart of the United Nations' Framework Convention on Climate Change (UNFCCC) (which the KP operationalized) is the adoption and implementation of climate mitigation policies. An increase in renewable energy (RE) consumption and energy efficiency (EE) constitutes an important part of climate mitigation policies. This is because fossil fuel consumption accounts for the majority of global anthropogenic GHG emissions (Edenhofer et al., 2011; Gielen et al., 2015). An increased deployment of both RE and EE in developed countries (and globally) has complementary effect in achieving the emission reductions needed to limit global temperature rise to less than 2°C (Gielen et al., 2015; IRENA and IEA, 2017).

A plethora of recent studies have pointed to a positive effect of the KP on GHG emissions (Maamoun, 2019; Grunewald and Martinez-Zarzoso, 2016; Aichele and Felbermayr, 2013). A policy relevant question however arises: how did the Kyoto protocol led to a reduction in GHG emissions? Did the KP led to emissions reduction via RE/EE? An understanding of how the KP affected RE and EE has important implications for both current and future climate mitigation policies.

In this paper, I analyzed the impact of KP on RE and EE. Examining the causal impact of KP on green growth is far from trivial. First, there is obvious selection into treatment: Annex B countries are mostly industrialized and transition economies in

[1] 2008 to 2012

the 1990s which makes them significantly different from non- Annex B countries. Secondly, the KP allowed Annex B countries to meet the targets mainly through national measures and three (3) flexible market-based mechanisms which allows cooperation with developing countries: International Emissions Trading (IET), Joint implementation (JI) and Clean Development Mechanism (CDM). Most importantly the CDM allows Annex B countries to cooperate with non-Annex B countries to engage in a GHG emissions reductions project such as renewable energy electrification project. The CDM may lead to a higher (lower) renewable energy penetration and higher (lower) EE in non-Annex B (non-Annex B) which violates the SUTVA. i.e., the RE/EE of Annex B countries may remain stable or decline while it increases in non-Annex B due to the CDM. Therefore, the differences in RE/EE between the two groups of countries is likely to overestimate the impact of the KP on RE/EE.

In order to deal with the above issues, I employed the difference-in-difference (diff-in-diff) approach combined with the Entropy Balancing (EB) method, a generalization of the conventional matching methods proposed by (Hainmueller, 2012) .The EB combined with the diff-in-diff allows me to identify the impact of the KP on RE/EE by comparing annex B and n on-annex B that are as similar as possible conditional observable characteristics, after accounting for country and time-specific factors. I found that the KP led to 3.4 percentage points increase in RE share of final energy consumption (FEC) and no significant effect on EE in countries that were legally bound by the KP. The results are robust to alternative definitions of RE/EE and the use of the Generalized Synthetic Control Method (GSCM).

The contribution of the present paper is three (3) folds. Unlike the existing studies, I examined the mechanisms through which the KP affected GHG emissions. Secondly, to the best of my knowledge this is the first study that used the EB method to study the impact of climate change policies. Lastly, I showed that the KP is one of the drivers of RE consumption in the advanced countries.

The rest of the paper is structured as follows. The empirical strategy and data are described in section 2 while the empirical results are presented in section 3. The robustness tests are presented in section 4 and conclusions in section 5.

2 Empirical Strategy

2.1 Empirical Model

To examine the impact of the KP on RE/EE, the following diff-in-diff model is specified;

$$y_{jt} = \beta_0 + \delta kyoto_{jt} + \alpha_j + \sigma_t + \epsilon_{jt} \tag{2.1}$$

Where y_{jt} is the outcome of interest (RE, EE) for country j at time t. $kyoto_{jt}$ takes the value of 1 if country j at time t is legally bound by the KP and zero otherwise. Following the existing literature, I used 2005 (the enforcement year) as the treatment period α_j and σ_t are country and year fixed effects respectively which accounts for time invariant heterogeneity and common shocks.

The average treatment effect (ATT) is given by δ ;

$$\begin{aligned} ATT = \delta = E\left(\Delta y | kyoto = 1\right) - E\left(\Delta y | kyoto = 0\right) \\ = \frac{1}{N}\left(\sum_{kyoto=1} \Delta y - \sum_{kyoto=0} \Delta y\right) \end{aligned} \tag{2.2}$$

The diff-in-diff methodology assumes that the evolution in the outcome variables would have evolved similarly in both the treated and control countries in the absence of the KP, popularly referred to as the parallel trend assumption. This assumption is unlikely to hold because the annex B countries differ significantly from the non-Annex B countries. Secondly, the Stable Unit Treatment Value (SUTVA) requires that the KP had no effect on countries that were not legally bound by them. This is also not likely to hold because the KP has flexible mechanisms which allowed those legally bound by it to cooperate with others not legally bound by it.

To deal with this issue, I used the Entropy Balancing (EB) method to create a comparable control group based on pre-treatment characteristics. Entropy balancing (EB) method developed by Hainmueller (2012), produces a set of observation-level weights that balances distributions across groups. EB constructs weights, such that distribution of baseline characteristics of the control group maximizes its similarity with the distribution of the baseline characteristics of the treatment group. The weighted R_{th} moments of the baseline characteristics of the control group are equal to the correspondent moments baseline characteristics in the treatment group.

The ATT based on combining the EB with the diff-in-diff is given by adjusting model 2.1 with the estimated weights ;

$$A\hat{T}T = \frac{1}{N}\left(\sum_{kyoto=1} \Delta y - \sum_{kyoto=0} \omega \Delta y\right) \tag{2.3}$$

Where N is the number of countries and ω is the estimated EB weight.

2.2 Data

The dataset used in the study spans from the period 1990 to 2012 and covers ... number of countries. In the main analysis, RE is defined as renewable energy consumption (% of FEC). EE is defined as the inverse of energy intensity (defined the ratio between energy supply and gross domestic product measured at purchasing power parity (PPP)). Both of these two variables are sourced from the World Bank´s World Development Indicators (WDI). Alternative definitions of these RE/EE are used in the robustness test; renewable energy consumption per capita (ktoe per population) and energy use per capita which were sourced from IEA AND WDI respectively.

The pretreatment characteristics used in the EB are greenhouse gas emissions per capita(exc LUF), real GDP per capita, Fossil fuel consumption (share of FEC), industry value added (% of GDP), Total Population and Bayesian Corruption Index. The definition of the variables and their various sources are The description of the variables used in the study and their sources can be found in Table A.2. The summary statistics are shown in Table A.1.

3 Empirical Results

3.1 Entropy Balancing

Before proceeding to the main analysis, I present the performance of the entropy balance in creating a comparable control group based on selected baseline characteristics. The average baseline characteristics of both the countries that are legally bound the KP (treatment) differ from those not legally bound (control) by the KP are shown in Table 1. The unweighted and weighted averages are shown in Panel A and B respectively. As can be seen in panel A, countries that are legally bound by the KP differ from those not legally bound significantly in several dimensions. Specifically, countries that are legally bound by the KP had on average a significant higher GHG emissions per capita , a significant higher real GDP per capita, a significant higher fossil fuel consumption and significant lower level of corruption than the control countries. They do not differ significantly in terms of population and industry value added (as percentage of GDP).

However, after applying the EB, no significant differences exist between the two groups in terms of baseline characteristics as shown in Panel B of Table 1.

3.2 Difference in Difference combined with Entropy Balance

I now present and discuss the results of the impact of the KP on green growth. The baseline results are shown in Table 2. Columns 1 and 4 presents the estimates of the unweighted regression while that of the weighted regression are shown columns 2 and 5 . Columns 3 and 6 also include control for the variables used in the EB. All the specification (columns 1 to 3) points towards a significant positive effect of the KP on RE. The unweighted regression shows a relatively higher magnitude compared to the weighted regression. Using the preferred specifications (columns 2 and 3), one can see that , the KP led to an increase in RE consumption by about 3.4 percentage points.

On the other hand, the results showed that the KP did not have any significant effect on EE. As can be seen from column 4 the unweighted diff-in-diff shows a significant positive effect on EE. However the diff-in-diff combined with the EB weights shows a negative and statistically insignificant impact on EE (columns 5 and 6).

Table 1: Summary Characteristics of countries in 2005

	Treatment	Control	Δ	p-value
Panel A: Before EB				
GHG emmissions per capita (exc LUF)	11.48	6.55	4.931	0.000
Real GDP per capita ('000s)	41.12	12.49	28.636	0.000
Fossil fuel consumption (share of FEC)	77.55	50.31	27.235	0.000
Industry value added (% of GDP)	25.73	27.25	-1.519	0.348
Total Population (millions)	30.41	34.42	-4.007	0.785
Bayesian Corruption Index	31.10	50.66	-19.563	0.000
Panel B: After EB				
GHG emmissions per capita (exc LUF)	11.56	11.55	0.007	0.998
Real GDP per capita ('000s)	41.12	41.09	0.035	0.997
Fossil fuel consumption (share of FEC)	77.55	77.54	0.010	0.999
Industry value added (% of GDP)	25.73	25.73	-0.001	1.000
Total Population (millions)	30.41	30.41	0.000	1.000
Bayesian Corruption Index	29.78	29.80	-0.022	0.997
Number of countries	28	161		

Notes: The table shows the average of selected baseline characteristics of countries legally bound by the KP (Treatment) and those not legally bound by the KP (Control) .

Table 2: of tax structures on renewable energy consumption

	Renewable Energy			Energy Efficiency		
	1	2	3	4	5	6
kyoto	8.952***	3.465**	3.382**	0.0182**	-0.00499	-0.00966
	(1.129)	(1.549)	(1.546)	(0.00789)	(0.0220)	(0.00846)
Observation	3363	3363	3363	3095	3095	3095
R-squared	0.966	0.962	0.964	0.870	0.863	0.928
EB Weights		✓	✓		✓	✓
Year FE	✓	✓	✓	✓	✓	✓
Country FE	✓	✓	✓	✓	✓	✓
Control variables			✓			✓

*Notes: The table presents the impact of KP on renewable energy consumption and energy efficiency. EB stands for Entropy Balance. Control variables include, GHG emissions per capita, fossil fuel consumption (share of final energy consumption), real GDP per capita, , industry value added (% of GDP), total population and Bayesian Corruption Index. Robust standard errors clustered at the country level are in parentheses. ***, **,* denotes 1%, 5% and 10% level of significance respectively.*

4 Robustness Tests

In this section I perform 2 main robustness tests. I first consider alternative definition of RE. Secondly, I test the robustness of the result using a different econometric strategy.

4.1 Alternative dependent variables

I consider two alternative definitions each for RE and EE. These are renewable energy consumption per capita, the growth of renewable energy consumption, energy use per capita and the growth of EE. As can be seen from Table 3, the main results still holds.The KP led to a significant positive effect on RE consumption per capita and the growth of RE consumption. Also a negative but statistically insignificant effect is found for energy use per capita and the growth of EE.

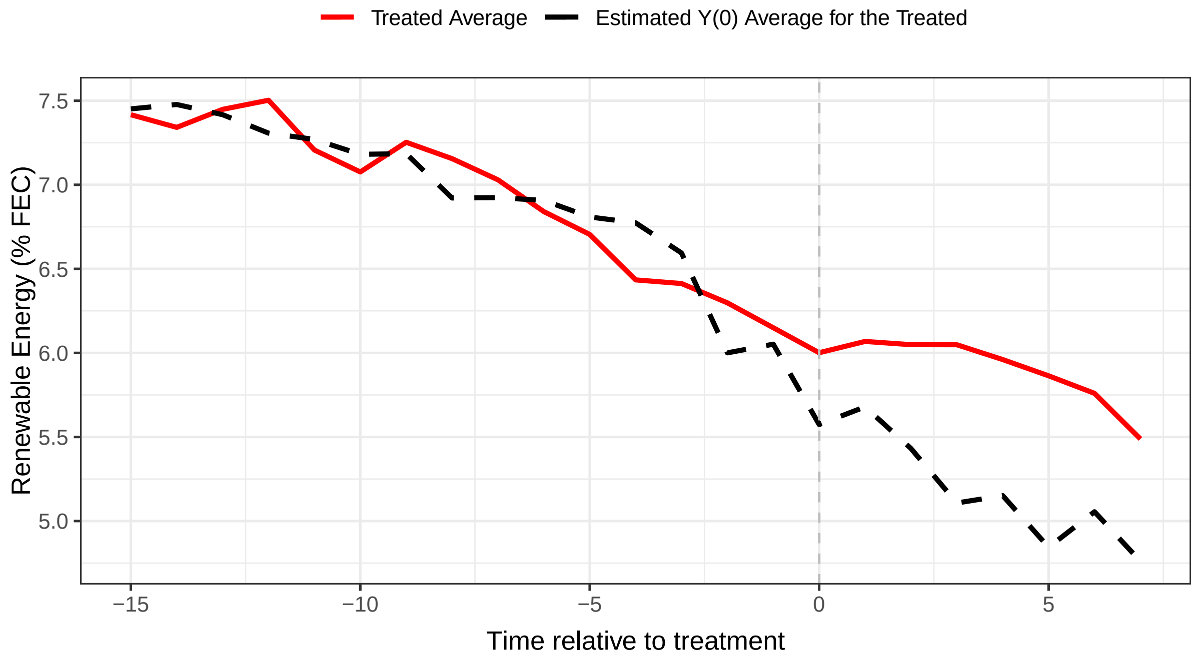
4.2 General Synthetic Control Method (GSCM)

The GSCM developed by Xu (2017) provides a data driven approach to create a synthetic counterfactual using information from the pool of aggregate units not exposed to the intervention. The idea similar to that of the SCM developed by Abadie et al. (2010). The advantage of the GSCM over SCM is that it easily allows for multiple treatment units and different treatment periods. Secondly, it allows easily for inference given that it provides uncertainty estimates such as the standard errors and confidence intervals. The result for RE is shown in Figure 1 while that of EE is shown in Figure 2. The evolution in RE and EE between the treated (red line) and the synthetic control (dashed black line) are shown in the top panel. It can be seen that the synthetic control matches that of the treatment group prior to the treatment year. It can be seen that the Business as usual (BAU) case i.e what would have happen in the absence of the KP showed that RE consumption would have declined and EE would have increased compared to what actually happened. The gap between the two (solid black line) together with the 95% confidence intervals are shown in the panel b of Figures 1 and 2.There is no statistically significant difference between the treated countries and the synthetic controls prior to the KP. However a positive and statistically significant effect is found for RE and a negative but statistically insignificant effect is found for EE. This is similar to the results obtained by combining the diff-in-diff with the EB.

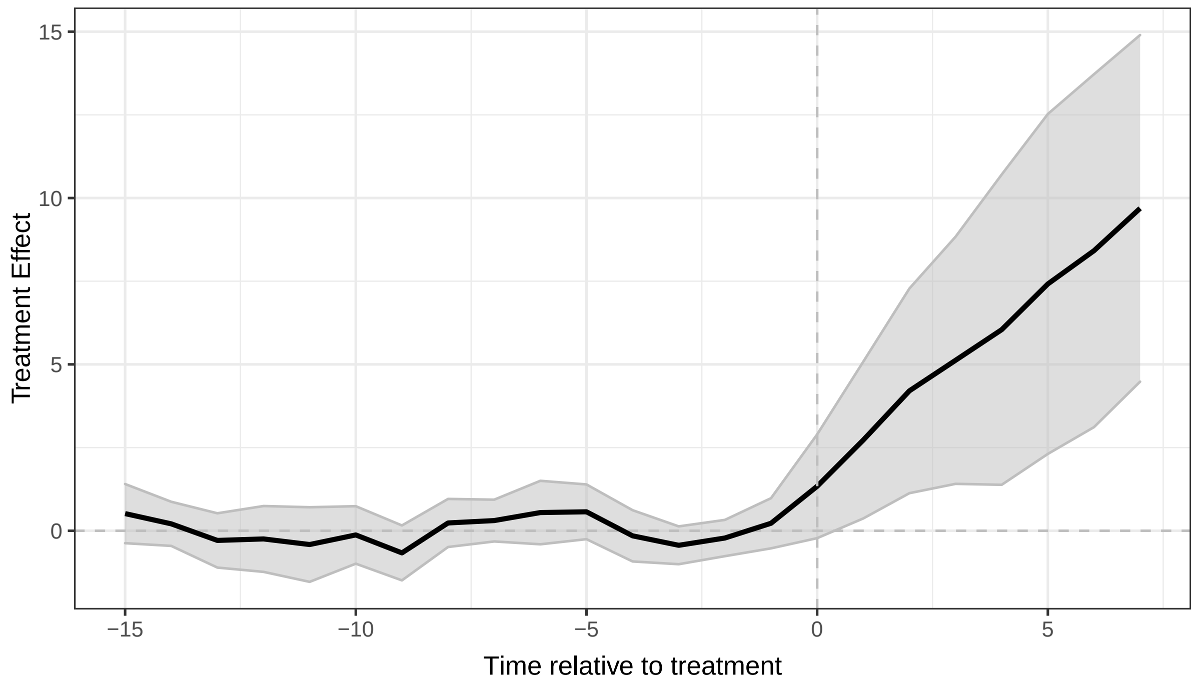
Table 3: Robustness Test: Alternative definitions of RE and EE

	Renewable Energy		Energy Efficiency	
	per capita	growth	energy use per capita	growth
kyoto	0.0000384**	0.118*	-189.4	-0.0169
	(0.0000153)	(0.0657)	(541.9)	(0.0108)
Observation	2835	2662	2667	3010
R-squared	0.964	0.172	0.934	0.187
EB Weights	✓	✓	✓	✓
Year FE	✓	✓	✓	✓
Country FE	✓	✓	✓	✓
Control variables	✓	✓	✓	✓

*Notes: The table presents the impact of KP on renewable energy consumption and energy efficiency. EB stands for Entropy Balance. Control variables include, GHG emissions per capita, fossil fuel consumption (share of final energy consumption), real GDP per capita, , industry value added (% of GDP), total population and Bayesian Corruption Index. Robust standard errors clustered at the country level are in parentheses. ***, **,* denotes 1%, 5% and 10% level of significance respectively.*



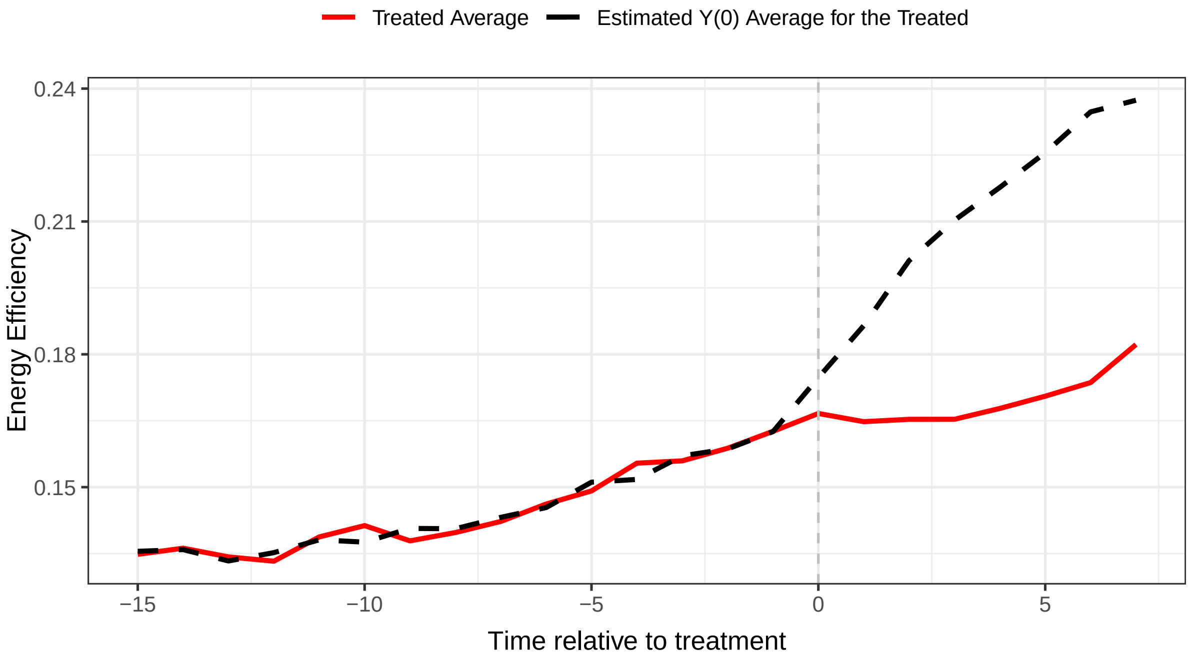
(a) Treated and synthetic control



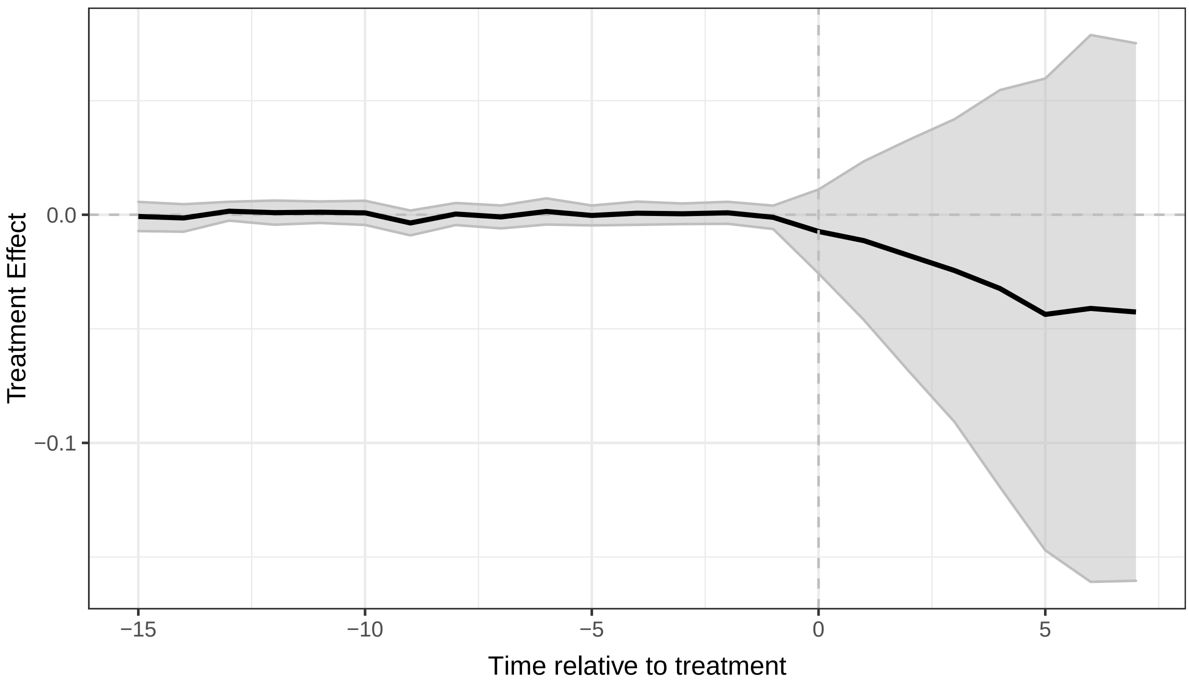
(b) Average treatment effect on the treated (ATT)

Figure 1: **Impact of Kyoto Protocol on renewable energy consumption**

Notes: The figure shows the results of the impact of the Kyoto protocol on renewable energy consumption using the generalized synthetic control method proposed by Xu (2017). Panel (a) shows the average renewable energy consumption (% of final energy consumption) for the treated countries and their synthetic controls. Panel (b) plots the average treatment effect on the treated (ATT). The shaded gray area indicates the 95% confidence intervals.



(a) Treated and synthetic control



(b) Average treatment effect on the treated (ATT)

Figure 2: **Impact of Kyoto Protocol on energy efficiency**

Notes: The figure shows the results of the impact of the Kyoto protocol on energy efficiency using the generalized synthetic control method proposed by Xu (2017). Panel (a) shows the average renewable energy consumption (% of final energy consumption) for the treated countries and their synthetic controls. Panel (b) plots the average treatment effect on the treated (ATT). The shaded gray area indicates the 95% confidence intervals.

5 Conclusion

Several international environmental agreements have been enacted to deal with climate challenge. At the core of some of these agreements are mitigation strategies such such renewable energy (RE) and energy efficiency (EE). One of such is the Kyoto Protocol (KP). Some recent studies have shown that the KP has been successful in reducing GHG emissions. However these studies are silent on the mechanisms through which the KP led to emissions reduction. In this paper, I examined two (2) of the channels through which the KP could potentially lead to emissions reduction. I found that the KP led to an increase in RE consumption but no significant impact on EE. The results are robust to alternative econometric method and different definitions of RE and EE.

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6 Appendix A: Additional Results

Table A.1: Summary Statistics

	N	Mean	Min	Max
Renewable Energy				
Renewable energy consumption (share of FEC)	3363	31.80	0.00	97.74
Renewable energy consumption per capita (ktoe/population)	2835	0.00	0.00	0.00
Growth rate of renewable energy per capita	2662	0.02	-1.00	4.19
Energy Efficiency				
Energy efficiency	3095	0.20	0.02	0.55
Growth rate of energy efficiency	3010	0.02	-0.55	0.89
Energy use per capita	2667	2153.46	9.55	18178.14
Others				
GHG emissions per capita (exc LUF)	3363	7.28	-3.68	58.92
Real GDP per capita ('000s)	3363	17.94	0.44	114.89
Fossil fuel consumption (share of FEC)	2646	63.87	0.00	100.00
Industry value added (% of GDP)	3243	27.31	5.05	87.80
Total Population (millions)	3363	43.17	0.05	1386.40
Bayesian Corruption Index	3363	45.81	6.45	74.96

Table A.2: Variables definition and source

Variable	Definition	Source
Renewable Energy	Renewable energy consumption (share of FEC)	WDI
	Renewable energy consumption per capita (ktoe/population)	IEA Energy Balance
	Growth rate of renewable energy per capita	
Energy efficiency	inverse of energy intensity (defined as the ratio between energy supply and gross domestic product measured at purchasing power parity (PPP)	WDI
	Growth rate of energy efficiency	
	Energy use per capita	WDI
Green house gas (GHG)	GHG emissions per capita (exc LUF)	Climate Watch
Real GDP per capita		WDI
Fossil fuel consumption	Fossil fuel consumption (share of FEC)	WDI
Industry value added	Industry value added (% of GDP)	WDI
Total Population		WDI
Corruption	Bayesian Corruption Index	Standaert (2015)