Air Emissions and Disparities Among Developing Nations: An Analysis of the Kyoto Protocol

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Abstract

Decisions made during early and transitional stages of development often involve observable increases to the levels of greenhouse gas emissions and fine particulate matter. Both are often found to be causal with problems involving climate change and adverse health expectations for young and elderly demographics. Consequently, these topics have garnered the most attention in talks of mitigating environmental externalities. While national policy has worked to decrease emissions and its adverse consequences on human well-being, air emissions very much remain an inter-temporal and global problem. We study the role that international environmental agreements have in the reduction of air emissions across countries. Specifically, we seek to determine whether the Kyoto Protocol of 1997 was effective over the length of its first round from 2005 to 2012. Under a difference-in-differences framework, we structure the protocol as a natural experiment on the basis of binding or nonbinding mandates across over 100 countries. We regress it, and other control variables, against three measures of air emissions and its adverse effects, as well as their logarithmic transformations. We find that the protocol under binding mandates is only effective in mitigating externalities associated with air emissions but not in reducing air emissions itself.

I. Introduction

Development economics generally concur that economies in the early stages of economic development will forego environmental preservation in favor of production activity and development, and will thus experience greater levels of environmental externalities (Grossman and Krueger 1991; Dinda 2004). These production-based decisions have resulted in higher, observable levels of greenhouse gas emissions (GHG) emissions (CO2, SO2, etc.) and fine particulate matter (PM2.5)[1]. Some of the most evident consequences of these externalities are adverse health expectations among young and older populations, rising sea levels, and increasing global temperature (Batisse et al. 2017; Boyce and Pastor 2013). Literature and policy implementation over the past twenty years that have analyzed the relationships between particulate matter and policy countermeasures years have been fueled primarily by growing concern of the long term implications of climate change and the irrecoverable environmental costs of many years of production and economic activity (*Laws and regulation*; Wang et al. 2018. One example is the Clean Air Act of 1970. It is among the most comprehensive internal countermeasures issued to address these concerns within the United States (Currie, Voorheis, and Walker 2020). With amendments added to it in 1977 and 1990, it has been frequently referenced when explaining trends in PM2.5 levels and air emissions in the context of federal intervention within the United States.

However, a great body of existing literature has also acknowledged the disproportionate nature of air emissions and PM2.5 exposure among underrepresented, developing regions in both developed, i.e. the United States, and developing countries abroad (Woo et al. 2019; Flanagan et al. 2019; Batisse et al. 2017). As such, robust analysis must question the efficacy of the policies similar to the Clean Air Act, and take into consideration the collective needs of said developing communities, relative to their stage of economic activity, when setting quotas on

[1]Henceforth, we use the term air emissions to discuss GHG and PM2.5 emissions for for simplicity of the discussion of our paper.

reductions in air emissions and particulate matter. One of the most debated attempts to remedy this conflict came with the passing of the Kyoto Protocol as an amendment to the United Nations Framework Convention on Climate Change (UNFCCC) in 1997 (Tessum et al. 2019; Tu 2018). It is distinguishable from normally binding agreements in that it takes into consideration contributions to current levels of air emissions of a specified country, and accordingly structures binding and nonbinding quotas on reduction in air emissions (*Kyoto protocol to the united nations framework convention on climate change*).

Our study focuses on the ratification of the Kyoto Protocol in over 100 countries. Our data is based on publicly available records from the World Bank's World Development Indicators (WDIs), the University of Oxford's online publication Our World in Data, and Transparency International's Corruption Perception's Index. We impose the data to a difference-in-differences technique to capture the effects of the policy from the start of its implementation in 2005 to the end of the first round, 2012. Specifically, our study analyzes whether the implementation of binding versus nonbinding agendas exasperate the impact of the protocol. We additionally control for key factors that are not so explicitly policy induced as part of developmental process, but still considered when making decisions of whether the protocol is binding or not. We then assess our findings relative to results of current work.

II. Literature Review

Dating back to as early as the 1950s, the tradeoffs of early development and environmental degradation have remained at the forefront of discussions of efficient practices of production activity (Kuznets 1955; Sprout and Sprout 1957). The realization that intense economic activity yields adverse health outcomes and devalued natural capital lead nations to establish long term plans based on cap and trade systems to mitigate the freedoms of their firms to openly pollute. In the United States, the Clean Air Act of 1970 was introduced to regulate the emissions of air toxins across the states. By the 1990s, it had received two additional amendments to further emphasize the need for a cleaner environment. At the same time, the establishment of trade policies, i.e. NAFTA and general wariness of openness of trade sparked a much larger debate among academics and government leaders of the role international trade had in environmental degradation. The results of this debate were embodied in international environmental agreements (IEAs) that shared common interests in remedying and prevention of transnational and international trade externalities. The Kyoto Protocol is one of the many examples of an international environmental agreement that have been proposed to combat climate change across the globe, and becomes the many topic of discussion for our study.

i. The Clean Air Act of 1970

Though structured to meet the needs of the well-being of the it's populace and communities, the Clean Air Act of 1970 has remained at the forefront of fuel efficiency policy in its implementation. While being one of the first programs to actively address the topic of environmental degradation at the federal level[2]. Since its first enactment in 1970, it's standing purpose has been "to protect and enhance the quality of the Nation's air resources so as to promote the public health and welfare and the productive capacity of its population...to encourage and assist the development and operation of regional air pollution prevention and control programs" (*Laws and regulation*). Documentation of the act of is elaborate and broken into seven titles. Each title addresses different aspects to reach goals of monitoring air flows for excessive pollutants; this includes formally defining hazardous air pollutants and land use authority, defining emission standards for moving sources, accounting for noise pollution, setting acid deposition controls, providing permits, and

[2]While the Air Pollution Control Act of 1955 was the first mandate implemented in the United States, it's enforcement was fairly lenient at the federal level and placed more emphasis on state and local governments' responsibilities. Other iterations of the Clean Air Act were legislated in 1963 and 1967 before being proactively enacted in 1970 (*Laws and regulation*).

developing tasks for stratospheric ozone protection.

ii. Air Emissions and Trade Policy in the 1990's

Since the Clean Air Act, levels of air pollution throughout the United States decreased and states since adopted stricter regulatory action under the Act's federal legislature. Despite the overall reduction of air emissions within the United States, as per Sonnenfeld and Mol 2002; Zahran et al. 2007, nation states are not solely responsible for addressing problems of environmental degradation within the borders of a country. The shares of air pollution continue(d) to remain largely disproportionate to the burdens of air pollution shared, and other forms of environmental degradation, by developing communities and impacted ethnicities, both nationally and abroad (Liévanos 2019; Boyce and Pastor 2013; Tetreault 2003; Wang et al. 2018). This concern hit a strong peak during the 1990s, when trade agreements across the globe were drafted to promote more efficient production activities and stronger international relationships (Grossman and Krueger 1991, 1995; *Trade Policy in the 1990s*. Thus, IEA's became policy measures of high interest for discussions of international environmental sustainability.

iii. IEAs, Climate Change, and the UNFCCC

While national policy is effective when implemented proactively, despite it's imperfect results, when common resources shared between nations begin to show deterioration (i.e. air quality at national borders, international waters, and outsourced capitol), the formation of IEAs become subject to potential environmental recovery. The UNFCCC, one of the most relevant coalitions under the United Nations to many of the IEAs passed today, was opened for formation at the Rio Earth Summit in 1992 and entered into full force by 1994. This collaborative effort's purpose is primarily an acknowledgement to growing concerns of climate change and a need to establish appropriate countermeasures as a unified entity with common interests; signatory are designated to Annex I parties, Annex II parties, Non-Annex I parties, or least developed countries (LDCs). Annex I parties include industrialised countries that were members of the OECD in 1992 (Eastern and Central Europe) and economies in transition (EITs). Annex II parties include Annex I countries that are not EITs. Non-Annex I parties include developing countries identified as vulnerable to economic impacts of climate change. LCDs are identified as having limited capacity to respond to climate change (*Parties non-party stakeholders*). From these designations, amendments to the convention are structured for parties to meet the mandates highlighted in each amendment. The first of these amendments was the Kyoto Protocol of 1997. From the start of the first commitment period, 2005, 192 countries had signed to the protocol (*Trade Policy in the 1990s*).

The Kyoto Protocol's overall goal builds on the purpose of the UNFCCC by means of facilitating, promoting, and enforcing compliance under commitments established with the protocol. This includes a guidance under a facilitative branch and an enforcement branch, each comprising ten members from a combination of the five official UN regions, the small island developing states, and the Annex I and non-Annex I parties (*Kyoto protocol to the united nations framework convention on climate change*). Each branch carries distinct roles of providing advice and facilitation to involved parties, relative to their stage of transition to market economies, to meet mandates set forth by the protocol and of ensuring Annex I parties are in compliance with the protocol, respectively. This IEA has garnered interesting discussion as, while countries that ratified the protocol were mandated to reduce greenhouse gas (GHG) and PM2.5 emissions within the first period of the protocol from 2005 to 2012, mandates were binding for industrialized countries of the Annex I party, but nonbinding for developed(ing) countries of the non-Annex I and LDC parties. This method of assigning agendas has led to split ideas of the effectiveness the protocol has actually had in its reduction of air emissions (Grunewald and Martinez-Zarzoso 2016; Maamoun 2019; Sandler 2017). On one hand, literature has argued that in placing non-binding mandates on non-Annex I countries as China and India who, despite its transitional stages of economic development, contribute exertionally to GHG and PM2.5 emissions undermine the impact of the protocol. On the other hand, even if the protocol provides more leeway for non-Annex I parties, such members are still provided guidance and recommendations under the mechanisms of the protocol. Given these differing perspectives over the implementation and effectiveness of the protocol, this study seeks to determine whether the protocol was effective in achieving its goal given its 'relative assignments' of mandates.

III. Data

The data summarized here come from publicly available databases. We obtain two separate measures of air emissions and a proxy of externalities associated with environmental degradation. The first two measures come from the World Development Indicators database of the World Bank: kilograms of CO2 emitted per dollars of 2017 purchasing power parity (PPP) and metric tons of CO2 emissions per capita. These two variables cover years from 1998 through 2019 for over 150 countries.

We use death rates per 100,000 people from ambient particulate air pollution to proxy the adverse health outcomes of air emissions. This data comes from the Our World in Data online publication. We reference the UNFCCC's List of Parties, available from the UNFCCC Process and Meetings, to set indicators for countries with binding and non-binding policies. In addition, we reference previous literature (Grunewald and Martinez-Zarzoso 2016; York 2005; Zahran et al. 2007; Fredriksson, Neumayer, and Ujhelyi 2007; Kuriyama and Abe 2018; Liddle 2015) and include control variables for population sizes, GDP growth, energy intensity, and renewable energy consumption to attempt to observe fundamental differences between countries' levels of development that are not explicitly represented in the treatment effect of the Kyoto Protocol. All are from the World Development Indicators database of the World Bank. Summary statistics for all quantitative variables are highlighted in Table I.

Table 1: *Summary Statistics*

	(1)	(2)	(3)	(4)	(5)
VARIABLES	N	mean	sd	min	max
CO2 per PPP	3,491	0.255	0.222	0.0136	1.978
CO2 per Capita	3,840	4.886	6.532	0.0163	67.31
Deaths	3,380	33.19	17.45	7.543	125.7
Log of CO2 per PPP	3,491	-1.622	0.704	-4.297	0.682
Log of CO2 per Capita	3,840	0.666	1.605	-4.118	4.209
Log of Deaths	3,380	3.373	0.512	2.021	4.834
GDP Growth	4,400	2.204	5.095	-62.38	121.8
Energy Intensity	3,444	6.548	5.238	0.00301	43.35
Share	3,776	30.16	30.28	0	98.34
Gov. Effectiveness	3,716	-0.0191	1.002	-2.484	2.437
Log of Population	4,766	15.08	2.424	9.141	21.06

Furthermore, we account for disparities in legislative enforcement across countries by including a control variable for 'federal corruption'; we use government effectiveness from the World Bank's Worldwide Governance Indicators. This index is based on perceptions of the quality of public services, federal commitment, and political transparency. The score ranges from -2.5 to 2.5, where -2.5 represents weak perceptions of government effectiveness and transparency and 2.5 represents strong perceptions of government effectiveness and transparency.

IV. Methodology

Our study analyzes the Kyoto Protocol as a natural experiment and, following suit of Grunewald and Martinez-Zarzoso (2016), accordingly implements a difference-in-differences framework to study the protocol's experimental effects. The use of difference-in-difference allows us to isolate the effects that take place before and after the protocol, making analysis of its impact more meaningful. To test the robustness of the difference-in-differences, we run four sets of models. Our simple OLS models takes on the form:

$$y = \beta_0 + \beta_1 x_T + \beta_2 x_C + \beta_3 x_{TR} + \mu \tag{1}$$

$$y = \beta_0 + \beta_1 x_T + \beta_2 x_C + \beta_3 x_{TR} + \gamma X + \mu \tag{2}$$

$$y = \beta_0 + \alpha + \epsilon + \beta_1 x_T + \beta_2 x_C + \beta_3 x_{TR} + \gamma X + \mu \tag{3}$$

$$y = \beta_0 + \beta_1 x_T + \beta_2 x_C + \beta_3 x_{TR} + \gamma X + \delta x_{TR} * (t - t_0) + \mu \tag{4}$$

where y represents the three response variables: kilograms of CO2 emitted per 2017 of PPP (CO2 per PPP), metric tons of CO2 emissions per capita (CO2 per Capita), and death rates per 100,000 people related to particulate air emissions (Deaths), as well as their logs. x_T and x_C represent binary variables for the time period and country effect, respectively. Note that while other studies have controlled for the year the protocol was ratified rather than the start of its implementation in 2005, we include numerous years after the protocol's implementation to account for any delayed time effects of the protocol. x_{TR} represents the difference-in-differences, i.e. the treatment of the binding mandates of the Kyoto Protocol, as the interaction of time period and country effect. X is the vector containing the control variables GDP growth rate (GDP Growth Rate), population size (Population), the ratio between energy supply and gross domestic product in terms of purchasing power parity (Energy Intensity), the share of renewable energies from final energy consumption (Share), and government effectiveness (Gov. Effectiveness). α and ϵ represent country an time fixed effects, respectively, and are included to account for unobservable factors that may cause spurious relationships among the control variables and y; they themselves are not of interest for our discussion. The $\delta x_{TR} * (t - t_0)$ term represents a linear time trend allowed to vary by treatment group. It is included to account for any changes within the treatment that result from each additional year in the observation period.

We expect the estimated β_3 parameter for the difference-in-differences to be significantly different from zero, indicating some treatment effect, negative or positive, on y. We expect the estimated parameters for GDP Growth Rate to positively impact y. As stated by previous literature, countries will make trade-offs between development and environmental degradation and choose to forgo the latter for the former. We expect the estimated parameters for Population to positively impact y; greater population levels, a characteristic more prominent in developing countries, will pollute more than less densely populated countries. We expect the estimated parameters for Gov. Effectiveness to negatively impact y, as countries with higher scores are perceived to be more effective, implying legislative entities are more likely to proactively enforce clean air practices and policy.

V. Results

Table I, II, III, and IV show regression results for OLS models (1), (2), (3), and (4), respectively. We discuss our primary findings by our six regressed variables.

Table 2: *Simple Model*

	(1)	(2)	(3)	(4)	(5)	(6)
VARIABLES	Deaths	CO2 per PPP	CO2 per Capita	Log of Deaths	Log of CO2 per PPP	Log of CO2 per Capita
Treatment	-5.231***	-0.0535***	-0.998***	-0.266***	-0.247***	-0.330***
	(0.834)	(0.0163)	(0.300)	(0.0219)	(0.0315)	(0.0535)
Ever	-5.358*	0.0261	4.727***	-0.124	0.302***	1.988***
	(3.203)	(0.0379)	(0.887)	(0.0899)	(0.105)	(0.163)
Post	-2.013***	-0.0222*	0.337	-0.0372***	-0.0273	0.224***
	(0.721)	(0.0115)	(0.207)	(0.0136)	(0.0241)	(0.0301)
Constant	36.93***	0.270***	3.489***	3.473***	-1.641***	0.0326
	(1.851)	(0.0257)	(0.651)	(0.0483)	(0.0697)	(0.147)
Observations	3,040	2,925	3,039	3,040	2,925	3,039
R-squared	0.050	0.008	0.068	0.070	0.018	0.216

Robust standard errors in parentheses

*** $p<0.01$, ** $p<0.05$, * $p<0.1$

Table 3: *With Controls*

	(1)	(2)	(3)	(4)	(5)	(6)
VARIABLES	Deaths	CO2 per PPP	CO2 per Capita	Log of Deaths	Log of CO2 per PPP	Log of CO2 per Capita
Treatment	-1.346	-0.000761	-0.307	-0.132***	-0.0626**	0.0278
	(0.914)	(0.0125)	(0.250)	(0.0264)	(0.0244)	(0.0426)
Ever	-8.119**	-0.0512*	-0.739	-0.199**	-0.0795	0.251*
	(3.532)	(0.0287)	(1.427)	(0.0931)	(0.0857)	(0.131)
Post	-2.139***	-0.0102	0.594***	-0.0591***	-0.0287	0.133***
	(0.784)	(0.00720)	(0.220)	(0.0193)	(0.0174)	(0.0310)
GDP Growth	0.188*	0.00144	-0.0564*	0.00594*	0.00122	0.000627
	(0.101)	(0.00115)	(0.0326)	(0.00300)	(0.00237)	(0.00383)
Log of Population	1.286**	0.00903*	-0.00622	0.0331*	0.0223	0.0243
	(0.593)	(0.00490)	(0.150)	(0.0176)	(0.0160)	(0.0297)
Energy Intensity	0.866***	0.0300***	0.387***	0.0113	0.0694***	0.0506***
	(0.293)	(0.00578)	(0.119)	(0.00932)	(0.00956)	(0.0150)
Share	-0.395***	-0.00581***	-0.102***	-0.0110***	-0.0206***	-0.0382***
	(0.0453)	(0.000535)	(0.0166)	(0.00125)	(0.00105)	(0.00254)
Gov. Effectiveness	-5.037***	-0.0354**	2.324***	-0.156***	-0.0696	0.523***
	(1.633)	(0.0139)	(0.543)	(0.0458)	(0.0434)	(0.0795)
Constant	24.74***	0.130	5.864**	3.265***	-1.684***	1.069**
	(9.371)	(0.0803)	(2.687)	(0.280)	(0.256)	(0.503)
Observations	2,381	2,414	2,449	2,381	2,414	2,449
R-squared	0.402	0.678	0.399	0.378	0.712	0.808

Robust standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1

Table 4: *With Time and Country Fixed Effects*

	(1)	(2)	(3)	(4)	(5)	(6)
VARIABLES	Deaths	CO2 per PPP	CO2 per Capita	Log of Deaths	Log of CO2 per PPP	Log of CO2 per Capita
Treatment	-4.750***	-0.0147	-1.383***	-0.202***	-0.0399	-0.0800**
	(0.784)	(0.0117)	(0.377)	(0.0207)	(0.0269)	(0.0364)
GDP Growth	0.0332	-0.000211	-0.000712	0.000202	-0.00101	0.000410
	(0.0227)	(0.000566)	(0.00628)	(0.000361)	(0.00106)	(0.000707)
Log of Population	-12.96***	0.0548	-7.464**	-0.180**	0.237*	-0.269**
	(4.679)	(0.0588)	(3.019)	(0.0700)	(0.142)	(0.120)
Energy Intensity	-0.174	0.0282***	0.0854*	-0.00710*	0.0468***	0.00656
	(0.252)	(0.00769)	(0.0496)	(0.00370)	(0.00866)	(0.00796)
Share	-0.203***	-0.00360***	-0.0660***	-0.00609***	-0.0204***	-0.0292***
	(0.0485)	(0.000539)	(0.0197)	(0.00129)	(0.00232)	(0.00406)
Gov. Effectiveness	-4.421***	-0.0219*	0.00794	-0.0747***	-0.0918***	0.0133
	(1.573)	(0.0119)	(0.367)	(0.0244)	(0.0322)	(0.0350)
Constant	246.9***	-0.646	121.5**	6.542***	-4.848**	5.592***
	(74.27)	(0.909)	(47.01)	(1.103)	(2.213)	(1.873)
Observations	2,381	2,414	2,449	2,381	2,414	2,449
R-squared	0.311	0.480	0.218	0.467	0.478	0.499
Number of id	151	155	158	151	155	158

Robust standard errors in parentheses

*** $p<0.01$, ** $p<0.05$, * $p<0.1$

Table 5: *With Fixed Effects and Linear Time Trend*

	(1)	(2)	(3)	(4)	(5)	(6)
VARIABLES	Deaths	CO2 per PPP	CO2 per Capita	Log of Deaths	Log of CO2 per PPP	Log of CO2 per Capita
Treatment	-0.101	0.00137	0.130	0.0136*	0.0226	0.0485***
	(0.304)	(0.00496)	(0.130)	(0.00809)	(0.0179)	(0.0171)
Ever	-	-	-	-	-	-
Post	0.317	-0.0175	3.093***	-0.00246	-0.128**	0.325***
	(1.400)	(0.0209)	(0.970)	(0.0317)	(0.0518)	(0.0569)
GDP Growth	0.0326	-0.000226	-0.000393	0.000197	-0.00104	0.000431
	(0.0227)	(0.000562)	(0.00625)	(0.000359)	(0.00104)	(0.000710)
Log of Population	-15.11***	0.0479	-8.241***	-0.281***	0.207	-0.334***
	(4.661)	(0.0599)	(3.031)	(0.0765)	(0.144)	(0.118)
Energy Intensity	-0.165	0.0282***	0.0897*	-0.00663*	0.0469***	0.00690
	(0.249)	(0.00770)	(0.0486)	(0.00365)	(0.00862)	(0.00798)
Share	-0.159***	-0.00350***	-0.0484**	-0.00392***	-0.0198***	-0.0277***
	(0.0487)	(0.000576)	(0.0214)	(0.00114)	(0.00247)	(0.00448)
Gov. Effectiveness	-4.303***	-0.0210*	0.0441	-0.0697***	-0.0893***	0.0166
	(1.589)	(0.0118)	(0.352)	(0.0250)	(0.0322)	(0.0348)
Ever Trend	-0.606***	-0.00391**	-0.0913	-0.0251***	-0.00911*	-0.00875*
	(0.120)	(0.00188)	(0.0661)	(0.00311)	(0.00501)	(0.00491)
Treatment Trend	-0.0213	0.00282	-0.178**	-0.00586	0.00117	-0.0135
	(0.161)	(0.00174)	(0.0698)	(0.00383)	(0.00620)	(0.00849)
Constant	277.7***	-0.550	132.7***	7.997***	-4.424**	6.536***
	(73.88)	(0.924)	(47.00)	(1.202)	(2.226)	(1.821)
Observations	2,381	2,414	2,449	2,381	2,414	2,449
R-squared	0.337	0.481	0.253	0.550	0.481	0.509
Number of id	151	155	158	151	155	158

Robust standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1

When we regress Deaths under a difference-in-differences framework, we find that

- The difference-in-differences, Treatment, is only statistically significant for the simple model and when we account for fixed effects, for which points we observe approximately 5 less deaths per 100k for countries that ratified the Kyoto Protocol with binding mandates on emission caps, all else held constant. Put in perspective of average deaths, this is approximately 0.3 of a standard deviation from the mean of 33.19, which is not insignificant.
- The population elasticity is statistically significant for each each of the three models. For every 10 percent increase to the country's population, we observe approximately 0.13 more deaths when we don't account for fixed effects, and 1.3 to 1.5 fewer deaths when we account for fixed effects and linear time trends, respectively, all else held constant.
- GDP Growth and Energy Intensity are only statistically significant for the specified model without fixed effects or linear time trends; for a 10 percentage increase in GDP Growth, we observe approximately 0.02 less deaths holding all else constant, and for Energy Intensity, we observe approximately 0.9 more deaths per 100k for a 1 unit increase of the energy production to GDP ratio, all else held constant. These results are not robust to the inclusion of fixed effects or linear trends.
- The share of renewable energy consumption is statistically significant for each model specification. For a 10 percentage increase to the country's share of renewable energy, relative to their total energy consumption, we observe approximately 0.04, 0.02, and 0.016 fewer deaths for models 2, 3, and 4, respectively, all else held constant.
- Government effectiveness is statistically significant for each model specification. For every 1 unit increase to the country's effectiveness score, we observe approximately 5 fewer deaths when we don't account for fixed effects, and 4.2 to 4.3 fewer deaths when we account for fixed effects and linear time trends, respectively, holding all else constant.

When we regress Log of Deaths under a difference-in-differences framework, we find that

- Treatment is statistically significant for all specified models. For models 1 and 2, we observe approximately 27% and 13.2% less deaths per 100k for countries that ratified the Kyoto Protocol with binding mandates on emission caps, all else held constant. Put in perspective of average log of deaths, this is approximately 0.5 and 0.25 standard deviations from the mean. When we include country and year fixed effects, we observe approximately 20% less deaths per 100k for countries that ratified the Kyoto Protocol with binding mandates, all else held constant. However, when additionally include linear time trends, the parameter estimates 1.36% This is approximately 0.4 and 0.04 standard deviations from the mean of 3.37.
- The population elasticity is statistically significant for each each of the three models. For every percentage increase to the country's population, we observe approximately 3.3% more deaths within a country when we don't account for fixed effects, and 18 to 28% fewer deaths when we account for fixed effects and linear time trends, respectively, all else held constant.
- GDP Growth and Energy Intensity are only statistically significant for the certain specified models. Without fixed effects or linear time trends; for a percentage increase in GDP Growth, we observe approximately 0.6% more deaths holding all else constant, and for Energy Intensity, we observe approximately 4.7% more deaths per 100k for a 1 unit increase of the energy production to GDP ratio when including fixed effects and a linear time trend, all else held constant.
- The share of renewable energy consumption is statistically significant for each model specification. For a percentage increase to the country's share of renewable energy relative, to their total energy consumption, we observe approximately 1.1%, 0.61%, and 0.4% fewer deaths for models 2, 3, and 4, respectively, all else held constant.
- Government effectiveness is statistically significant for each model specification. For every 1 unit increase to the country's effectiveness score, we observe approximately 15.6%, 7.5%,

and 7% fewer deaths for models 2, 3, and 4, respectively, all else held constant.

When we regress CO2 per PPP under a difference-in-differences framework, we find that

- Treatment is only statistically significant for model 1, at which point we observe approximately 0.05 less kilograms of CO2 emissions for countries that ratified the Kyoto Protocol with binding mandates on emission caps, all else held constant. Put in perspective of average kilograms of CO2 emissions, this is approximately 0.23 of a standard deviation from the mean 0.25.
- The population elasticity of is only statistically significant for model 1. For every 10 percent increase to the country's population, we observe approximately 0.0009 more kilograms of CO2 emissions per 2017 PPP dollar's worth of GDP, all else held constant.
- GDP Growth is not statistically significant for any of the specified models.
- Energy Intensity is statistically significant for each model specification. For a 1 unit increase of the energy production to GDP ratio, we observe approximately 0.03 more kilograms of CO2 emissions for models 2, 3, and 4.
- The share of renewable energy consumption is statistically significant for each model specification. For a 10 percentage increase to the country's share of renewable energy relative to their total energy consumption, we observe between 0.0005 and 0.0003 fewer kilograms of CO2 emissions for models 2, 3, and 4.
- Government effectiveness is statistically significant for each model specification. For every 1 unit increase to the country's effectiveness score, we observe approximately 0.005 to 0.002 fewer kilograms of CO2 emissions per 2017 PPP dollar's worth of GDP for models 2, 3, and 4.

When we regress Log of CO2 per PPP under a difference-in-differences framework, we find

- Treatment is only statistically significant for models 1 and 2, at which point we observe approximately 24.7% and 6.2% less kilograms of CO2 emissions per 2017 PPP dollar's worth of GDP for countries that ratified the Kyoto Protocol with binding mandates on emission caps, respectively, all else held constant. Put in perspective of the mean, this is approximately 0.35 and 0.09 standard deviations from the mean -1.62.

- The population elasticity of is only statistically significant to the inclusion of year and country fixed effects, at which point we observe that for every percentage increase to the country's population, we observe approximately 23.7% more kilograms of CO2 emissions.
- GDP Growth is not statistically significant for any of the specified models.
- Energy Intensity is statistically significant for each model specification. For a 1 unit increase of the energy production to GDP ratio, we observe approximately 7% more kilograms of CO2 emissions for model 2, approximately 7% more for models 3 and 4.
- The share of renewable energy consumption is statistically significant for each model specification. For a percentage increase to the country's share of renewable energy relative to their total energy consumption, we observe approximately 2% fewer kilograms of CO2 emissions for models 2, 3, and 4.
- Government effectiveness is only statistically significant for models 3 and 4. For every 1 unit increase to the country's effectiveness score, we observe approximately 9% fewer kilograms of CO2 emissions for models 3 and 4.

When we regress CO2 per Capita under a difference-in-differences framework, we find that

- Treatment, is only statistically significant for the simple model and when we account for fixed effects, at which point we observe approximately 1 and 1.38 less per capita tons of CO2 emissions for countries that ratified the Kyoto Protocol with binding mandates on emission caps, respectively, all else held constant. Put in perspective of the mean, this is approximately 0.15 and 0.2 standard deviations from the mean of 4.89.
- The population elasticity of is only statistically significant for models 3 and 4. For every 10 percent increase to the country's population, we observe approximately 0.75 and 0.82 fewer

per capita tons of CO2 emissions, respectively, all else held constant.

- GDP Growth is only statistically significant for the specified model without fixed effects or linear time trends; for a 10 percentage increase in GDP Growth, we observe approximately 0.005 less per capita tons of CO2 emissions, holding all else constant.
- The share of renewable energy consumption is statistically significant for each model specification. For a 10 percentage increase to the country's share of renewable energy relative to their total energy consumption, we observe approximately 0.01, 0.006, and 0.005 fewer per capita tons of CO2 emissions from models 2, 3, and 4, respectively, all else held constant.
- Government effectiveness is only statistically significant for model 2, where we find that for every 1 unit increase to the country's effectiveness score, we observe approximately 2.3 more per capita tons of CO2 emissions, holding all else constant.

When we regress Log of CO2 per Capita under a difference-in-differences framework, we find

- Treatment, is statistically significant for models 1, 3, and 4, at which point we observe approximately 33%, 8%, and 5% less per capita tons of CO2 emissions for countries that ratified the Kyoto Protocol with binding mandates on emission caps, respectively, all else held constant. Put in perspective of the mean, this is approximately 0.2, 0.05, and 0.03 of a standard deviation from the mean of 0.66.
- The population elasticity of is statistically significant for models 3 and 4. For every percentage increase to the country's population, we observe approximately 27% and 33.4% fewer per capita tons of CO2 emissions, respectively, all else held constant.
- GDP Growth is not statistically significant for any of the specified models.
- Energy Intensity is only statistically significant for model 2, for which we observe a 1 unit increase of the energy production to GDP ratio, we observe approximately 5% more per capita tons of CO2 emissions, all else held constant.
- The share of renewable energy consumption is statistically significant for each model

specification. For a percentage increase to the country's share of renewable energy relative to their total energy consumption, we observe approximately 3.8%, 2.9%, and 2.7% fewer per capita tons of CO2 emissions when we, respectively, all else held constant.

- Government effectiveness is only statistically significant for model 2. For every 1 unit increase to the country's effectiveness score, we observe approximately 50% fewer per capita tons of CO2 emissions, holding all else constant.

VI. Discussion

i. Implications

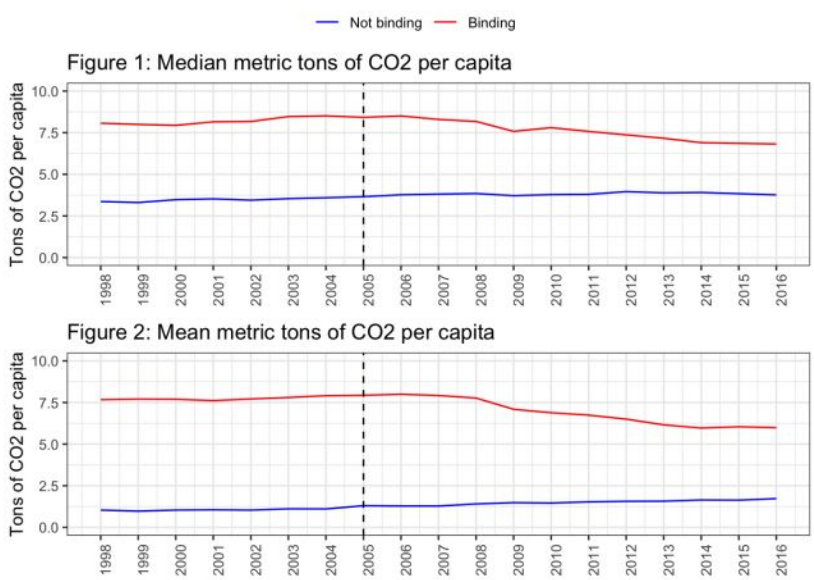
Findings provide insight of the nature binding mandates had on air emissions and its externalities. Most prominent is the robustness of results for the log of deaths per 100 thousand people. This means that even when accounting for unobersavable effects specific to each country that ratified the Kyoto Protocol under the specified conditions of our study the, difference-in-differences for countries with binding mandates were able to see continued improvements to health outcomes and decreases in overall deaths, even in the years following the end of the first round, results were still prominent. Moreover, considering the effects of other controls on air emissions provide further validation of the protocol's effects and are also worth considering when devising IEAs.

While findings are meaningful to discussions of the role IEAs play in the reduction of air emissions, our study is not without limitations.

ii. Drawbacks and Future Work

One key problem with the use of GDP and environmental regulation issues of underlying endogenous nature with other controls. It's likely that the unobservable impacts of location choice related to provision availability of infrastructure and agglomeration of industries that are high air emission contributors that are included as fixed effects in the model are correlated with these other regressors, even with economical informed selection process for inclusion in the model. Furthermore, the nature of our choice of policy intervention in its binding and nonbinding is likely induced by the expectations of future GDP growth through the duration of the first round of the Kyoto Protocol. This leads to unforeseen problems of multicollinearity of our regressors and inadvertent bias parameter estimates (Millimet and Roy 2016; Wu et al. 2020). To correct for such problems, previous literature have employed the use of spatial Durbin models to control for spatial spillover effects through the assignment of spatial weights to each observation and dynamic threshold panel models to study the effects of spatial heterogeneity on environmental outcomes (Wu et al. 2020).

The validity of the difference-in-differences should also be questioned when interpreting results under the inclusion of linear time trends. Further inspection of the data in Figures 1,2, and 3 indicate that the movement of the regressed variables, particularly for kilograms of CO2 emissions per PPP dollars of GDP, were initially following different consumption patterns for air emissions.



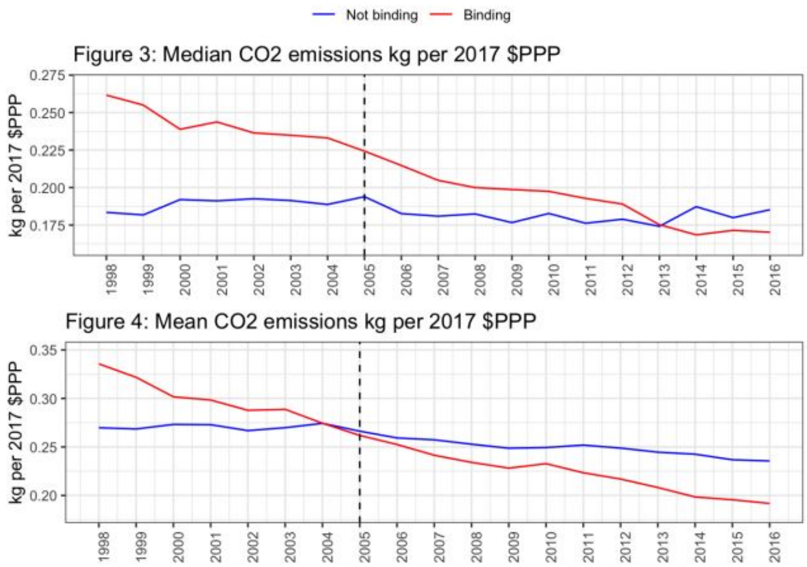


Figure 3: Median CO2 emissions kg per 2017 $PPP

Figure 4: Mean CO2 emissions kg per 2017 $PPP

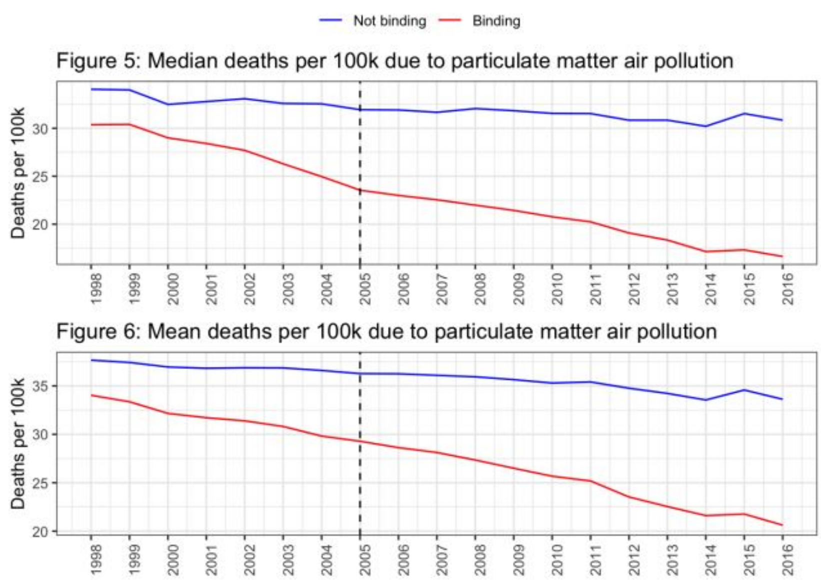


Figure 5: Median deaths per 100k due to particulate matter air pollution

Figure 6: Mean deaths per 100k due to particulate matter air pollution

This provides misinterpretation of parameter estimates that arise when assumptions of parallel trends do not hold. To correct for this problem, future work could match countries of similar consumption patterns from the pre-treatment group. However, this is often not sufficient, as simply analyzing differnces-in-differences on the basis of similar trends does not imply that trend and level effects will be well balanced (Lindner and McConnell 2019). A more robust approach that has gained traction in recent years would be to impose the data to a synthetic controls methods (SCM) or, even more recently, to a generalized synthetic controls methods (Abadie, Diamond, and Hainmueller 2010; Xu 2017; Maamoun 2019). Under SCM, trends are assumed to not be parallel and instead assign a calculated counterfactual that countries would have experienced would the event not have been implemented; results are thus more comparable for policy recommendation (Abadie, Diamond, and Hainmueller 2010). More recent GSCM builds on the SCM by also including interactive fixed effects of country specific constants/intercepts and time varying coefficients (Xu 2017). Both are worth applying to the Kyoto Protocol, especially for analysis of trajectories that can assist decisions of ratifying newer IEAs.

Nonetheless, our results still provide important insight of how the Kyoto Protocol reduced externalities related to air emissions when mandates on country emissions are strict is worth further studying and collaboration for future IEAs to target negative health outcomes of emissions. Careful consideration when devising IEAs to address air emissions should take into account the changes to population sizes and the rate at which populations consume renewable energy resources, the the degree to which the production of renewable energy makes up a country's total GDP, and degree of effectiveness each participant's government affluence have to follow up on emission restrictions. Incorporating future work recommendations will provide even more insightful, and accurate, analysis.

VII. Conclusion

We examine the impact the Kyoto Protocol had in the reduction of air emissions and their externalities across numerous countries under a difference-in-differences analysis. We find that the protocol under binding mandates only diminishes the externaities associated with air emissions but is not effective in reducing air emissions under the inclusion of country specific and time fixed effects or time trends. Applying matching techniques, SCM, and GSCM to our analysis would provide further insight of the role binding mandates of the Kyoto Protocol had in reducing air emissions across countries. But our results still provide discussion points of expected results on externalities associated with air emissions.

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