International Environmental Agreements: Empirical Evidence of a Hidden Success

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Abstract

How effective was the Kyoto protocol? International Environmental Agreements (IEA) have been on the rise over the past four decades; however, thus far their effectiveness is controversial, especially after the alleged failure of the Kyoto protocol. This paper aims to empirically test whether the protocol was successful in reducing greenhouse gas (GHG) emissions of participating parties or not. The main contribution of this paper is that it applies the generalized synthetic control (GSC) method for the first time to test the effectiveness of the Kyoto protocol by comparing the emissions of the industrialized countries with a "No- Kyoto" counter-factual scenario that represents the expected emissions in the absence of the protocol. Results show that the protocol was successful in reducing the emissions of the ratifying countries approximately by 7% below the emissions expected under a "No-Kyoto" scenario.

Keywords: Treatment effects, International agreements, International Public Goods, Global warming.

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1 Introduction

Climate change and the problem of global warming have climbed to the forefront of global concern and become the center of scientific as well as global public debate. Not only due to its increasingly negative effects on current ecological and economic systems, but also due to the uncertainty that surrounds the causes as well as future effects of global warming. The air pollution levels have been exponentially increasing since the industrial revolution and current emissions of anthropogenic greenhouse gases are 70% more than they were 40 years ago [Barrett et al., 2014]. Given the proven negative effects of the increased emissions on the current ecological system as well as the uncertainty that surrounds the future effects, climate change and in specific the problem of global warming has been increasingly attracting the attention of the public [Mitchell, 2003; Libecap, 2014].

Taking into account the trans-boundary nature of air pollution, global collective action is needed to target global such a problem [Feeny et al., 1990; Arce M. and Sandler, 2001; Aakvik and Tjøtta, 2011; Wiener, 2007; Livermore and Revesz, 2017].Accordingly, international organizations and governments have been trying to limit global emissions and find a solution to the escalating problem.Therefore, it comes as no surprise that ever since the late 1970's the number of international agreements signed and policies set trying to reduce air pollution has been exponentially increasing. One of the most prominent treaties is the Kyoto protocol, which is a part of the UN framework convention on climate change (UNFCCC)[Barrett, 1994; Mickwitz, 2003; Mitchell, 2003; Faure and Lefevere, 2012; Vollenweider, 2013].

The protocol is one of the most inclusive as well as ambitious agreements targeting the reduction of air pollution. The main aim of the protocol was to reduce the greenhouse gas (GHG) emissions as they have been shown to have a detrimental effect on the global climate. The effectiveness of these agreements in general and the Kyoto protocol in specific is still debatable. Previous literature [Aichele and Felbermayr, 2012; Grunewald and Martinez-Zarzoso, 2016; Almer and Winkler, 2017] has analyzed the effectiveness of the Kyoto protocol in reducing harmful emissions using different empirical methods and has provided conflicting results. Given the specificities of environmental (air pollution) data as well as the nature of international agreements and the rules and obligations associated with it, the current empirical evidence is insufficient and hence the need for the adequate evaluation for environmental policies has become essential, especially with the increased number of agreements being signed and ratified [Barrett, 1994; Mickwitz, 2003; Vollenweider, 2013; Livermore and Revesz, 2017]

The general empirical approach to assess the effectiveness of an environmental agreement is to compare current pollution levels with the "would-have been" pollution rate if the policies were not imposed. The goal is to find the suitable counter-factual scenario and accordingly find the "would-have been" pollution rate in an untreated country in comparison to a country that had a policy set with the aim of pollution reduction. [Helm and Sprinz, 2000] use game theoretic models to find the counterfactual and while it is theoretically elegant it has some empirical concerns with regards to the accuracy of its predictions as well as its ability to identify causal effects over time, given that the data is subject to possible variability and many confounding variables that are not always observable as well as the presence of important spatial and temporal dimensions [Vollenweider, 2013]. Turning a blind eye on these characteristics would lead to inaccuracy as well as contradiction in interpretation[Scott, 2007].

A more preferred and commonly applied method is to investigate the impact of environmental policies using regressions. However, the voluntary nature of the agreements gives rise to the presence of unobservable confounders that lead to a bias (self-selection bias) due to the fact that the reasons why each government voluntarily takes the step to participate in an agreement differ from one government to another and are most likely endogenous to country-specific characteristics[1]. This self-selection bias needs to be taken into account when evaluating the effectiveness of policies to avoid biased results, [Bennear and Coglianese, 2005; Vollenweider, 2013; Aichele and Felbermayr, 2012]. To overcome the previously mentioned limitations more recent research has moved to the usage of the difference-in differences (D-I-D) method. Vollenweider; Grunewald and Martinez-Zarzoso. Vollenweider [2013] used the D-I-D to test the effectiveness of the Gothenburg protocol one of the protocols of the Long-run Transboundary Air Pollution (LRTAP) agreements[2]. The problem with the D-I-D though is that it sets forth

[1]Controlling for some factors may reduce the bias but is still insufficient as the confounders are usually not known and hence regression models would not provide the most accurate results

[2]That targets the reduction of 4 harmful polluting gases, namely SO_2, NO_x , NH_3 and VOC.The paper shows that the Gothenburg's protocol had negative but insignificant effects on the emissions of SO_2 and NO_x emissions

the assumption that the unobservable differences are constant over time, which in the case of environmental impacts is not a very accurate assumption due to the existence of confounders that vary over time. To overcome the lack of parallel trends, matching has been used before the D-I-D estimation as in Grunewald and Martinez-Zarzoso [2016], so that they are able to make the control and treated group more similar to each other and hence limit the effects of the unobservable time varying confounders. In their paper, they tested the effect of ratifying the Kyoto protocol on CO_2 emissions of the industrialized countries that were legally bound by the protocol to reduce their emissions. Their results show a significant 7% reduction of emissions in the countries bound by the protocol. And while the use of matching has its merits, it does not necessarily ensure that the trends before treatment will be parallel and accordingly the estimates would not be fully valid [Bennear and Coglianese, 2005; Grunewald and Martinez-Zarzoso, 2016; Xu, 2017].

In this case the use of the synthetic control method (SCM) seems to be the most empirically feasible method for application due to the fact that it does not assume the presence of parallel trends [Abadie et al., 2010]. It formulates from the control group (non-treated group of countries) a synthetic counter-factual that behaves very similar to the original treated unit in the years prior to the treatment, thus facilitating accurate comparison between the treated unit and its hypothetical behavior in the case of no treatment [Vollenweider, 2013]. Almer and Winkler [2017] analyzed the effectiveness of the Kyoto protocol on 15 countries (out of 36 countries mentioned in Annex B in the protocol) using the SCM, where they found negative but non significant effects on the treated countries. The main limitation of this paper lies in the fact they disregard the fact that the Kyoto protocol is a collective action initiative that provided some market-based tools such as the international emission trading (IET) scheme as well as others to facilitate the reduction of the participating group. Analyzing countries individually would disregard these facilitating tools and hence provide inaccurate results.

Given that the purpose of this paper is to analyze the effectiveness of the Kyoto protocol as international agreement aiming to collectively reduce trans-boundary air pollution, estimating the effects on individual countries would not serve this aim. There have been suggestions by [Abadie et al., 2010] to aggregate the treated units into a single treated unit and aggregate the control units into groups. However one problem with this approach is that statistical significance is difficult to detect given the reduced number of control units after aggregation. Kreif et al. (2016) propose an extension of weighing the control units to match the average pretreatment outcomes of treated unit. However, Xu [2017] provides a more accurate and efficient method, the generalized synthetic control (GSC) method that allows for having multiple treated units as well as providing frequentist uncertainty estimates that are more reliable than the placebo tests used in SCM, which proves to be more efficient as well as easily interpretable compared to the original SCM. It also unifies the SCM with interactive linear fixed effects model to account for unobservable factors to reduce the potential endogeneity resulting from omitted variables.

The contribution of this paper is twofolds. It introduces the usage of the generalized synthetic control method-introduced by Xu [2017] for the first time to analyze the effectiveness of international agreements; in general such analysis has been subject to problems such as endogeneity and Xu [2017] provides a method-GSC-that facilitates such an analysis. In addition it contributes to the existing literature on the effectiveness of the Kyoto protocol by proposing that the protocol's effectiveness in its preventative ability rather than net emission reductions. As well as shed some light on some of the specifications of the Kyoto protocol that were subject to criticism such as "Hot-air"[3] and whether such criticism was in place or not.

Analyzing data on the greenhouse gas emissions, results show that the Kyoto protocol has been successful in reducing the emissions of the countries that were legally bound by the protocol by approximately at least 7% below their expected business-as-usual (BAU) levels. Also checks were run to check whether the criticism against the protocol was in place or not, and the results show that overall the Kyoto protocol has consistently led to a significant reduction in the GHG emission of the legally bound parties.

The paper is divided into five sections. The following section section discusses the kyoto protocol in more details and the hypothesis set forth in this paper. The third section discusses the empirical strategy and the specifications of the GSC method. The fourth section analyses the results and the last section concludes.

[3] Assigned amounts of the former soviet union countries, which were deemed to be more than their expected BAU

2 The Kyoto protocol

2.1 Background

The Kyoto protocol is one of UNFCCC targeting the reduction of harmful gases and it is one of the most infamous IEAs. The Kyoto protocol has been criticized before it came into force[Barrett, 1998; Böhringer and Vogt, 2004] and even more after its first commitment period ended in 2012 and the problem of global warming was still escalating [Aichele and Felbermayr, 2012; Nordhaus, 2015]. In December 1997, the Kyoto protocol was adopted by more than 180 countries and was opened for signature in March 1998. It came into force in 2005 after the conditions of enforcement were fulfilled. These conditions were that at least 55 countries had ratified the protocol and among those who ratified from the industrialized countries (mentioned in Annex I in the UNFCCC and Annex B in the Kyoto protocol), their GHG emissions should account for at least 55% of total emissions level in 1990 [United Nations, 1998; Breidenich et al., 1997]. It was ratified by 192 countries and in this sense it is an international agreement, however, it sets legally binding targets to only a group of countries known as Annex B countries (industrialized countries), which is assumed to undermine its effectiveness as this means that the agreement in fact a sub-global one [Wiener, 2007].

The legally binding targets stated in the protocol require the industrialized countries to reduce their emissions to be on average 5.2% less than their emission levels in the base year 1990 [4] during the first commitment period [United Nations, 1998; Breidenich et al., 1997; Aldy and Stavins, 2013].These fixed targets are basically assigned emission amounts that should not be exceeded by any party mentioned in Annex I that ratified the protocol [5] [Breidenich et al., 1997]. The targets set by the protocol are not annual target reduction in emissions; the targets are set so that they are reached within a commitment period, which is set to be 5 years. Accordingly the assigned amounts are the product of base year emissions (typically 1990 levels) and the targeted emission reduction and then multiplied by 5 (the number of years of the 1st commitment period), of course these amounts may vary based on the involvement of a party in

[4] The base year is set to be 1990 for most industrialized countries except for the newly capitalized countries (eastern European countries), who were allowed to choose a different year

[5] These assigned amounts are not uniform as the parties involved weren't able to unanimously agree on one-target-fits-all, so every country has a different targeted reduction based on their economic condition

the emissions trading mechanisms provided by the protocol [Breidenich et al., 1997; Böhringer, 2003].

2.2 Criticisms

The Kyoto protocol and its effectiveness have been and still are controversial. On the one hand it is believed to be an essential step, on the other hand it is regarded as an weak treaty with flawed architecture [Barrett, 1998; Aichele and Felbermayr, 2012; Faure and Lefevere, 2012; Nordhaus, 2015]. Nevertheless, it is fair to say that Kyoto protocol has had some virtues. The protocol established clear-cut targets to be reached in a specific time period, and while this timetables approach has been criticized[Nordhaus, 2015], the specificity of the protocol's targets as well as the time period was necessary given that it is a legally binding treaty and that the climate problem might be time-sensitive [6] [Böhringer, 2003; Aldy and Stavins, 2008]. Additionally, it has a comprehensive approach in the sense that it considers carbon sequestration and the use of sinks as an acceptable way of reducing the GHG emissions[7][Böhringer and Vogt, 2004]. More importantly it recognizes domestic sovereignty; so essentially each country has the right to decide on the policies and the measures necessary to achieve its targets [Breidenich et al., 1997].The flexibility is not just limited to domestic choice of policies; rather it extends also to the international context by offering three flexibility instruments that promote cooperation between the countries; namely the Joint Implementation (JI), the International Emission trading (IET) and the Clean Development Mechanisms (CDM). These mechanisms facilitate for countries to achieve their targets jointly or separately[Böhringer, 2003; Aldy and Stavins, 2008; Faure and Lefevere, 2012].

According to the UNFCCC principle of "Common but differentiated responsibilities", the protocol legally binds the industrialized countries to reduce their GHG emission to a certain percentage-differs from country to country based on their conditions- below their 1990 levels (with the exception of some countries that use another base year) and improve sinks. Under this principle the UNFCCC embraces distributional equity and aims at achieving fairness by

[6] At the time of the protocol, it was well established that increased temperature would have severe harmful effects, however the magnitude of the risk and the expected period were the still subject to scientific uncertainty

[7] So the targets are set based on the net amounts of GHG emissions after accounting for reduction due to the sinks (forests)

making the countries that contributed a bigger share to the accumulated GHG stock in the atmosphere shoulder a bigger share of the responsibility of emission mitigation [UNFCC, 1992; Breidenich et al., 1997; Aldy and Stavins, 2008; Faure and Lefevere, 2012; Aldy and Stavins, 2013]. However, as well intended as this principle sounds it led to problems of leakage and free riding, not to mention that the world has changed greatly in terms of the production centers since the adoption of the protocol and some of the current major emitters where not sufficiently included in the protocol[8] [Aldy and Stavins, 2008, 2013].

The differentiation in the obligations of the parties -while sensible at the time- leads to a problem as it just limits the legal obligation within the borders of a small number of countries and leads to the problem of leakage [Böhringer and Vogt, 2004; Nordhaus, 2015]. The fact that leakage occurs severely undermines the effectiveness of the Kyoto protocol. First, since air is trans-boundary shifting the emissions across borders does not lead to any effect; in fact it could be counterproductive if the developing economies exceed the production of the industrialized world [Aldy and Stavins, 2013]. As a result the developing countries would have a comparative advantage in the production of carbon-intensive goods and services. The spatial shift of production of carbon intensive goods and services is known as leakage; either the industrialized countries shift their production to these countries- due to the lack of strict of regulations on carbon and other GHG emissions- or the developed countries seize the opportunity and shift to more carbon intensive production [9] [Aldy and Stavins, 2008; Aichele and Felbermayr, 2012; Aldy and Stavins, 2013]. Naturally, these above-mentioned reasons led to the opposition of some of the industrialized countries of some of the protocols obligations if not a complete refusal of ratification-as in the case of the US [Böhringer and Vogt, 2004].

Additionally the amounts assigned to the former soviet-union countries were larger than their expected Business-as-usual (BAU) emissions levels-known as "hot-air"- which opened the opportunity of increasing emissions or selling the extra assigned amounts, without any reduction in emissions levels. Another of the protocol's weaknesses is that it was criticized by having inef-

[8] The causality chain might be subject to discussion, whether the leakage led to the shift of production or not. However, it's assumed here that the shift was already in process with the Asian tigers already on their way

[9] To clarify, the developing countries that ratified the protocol are legally bound to report their emissions and exert an effort towards reducing the emissions but do not have specific target to be fulfilled by the 1st commitment period as the industrialized countries are

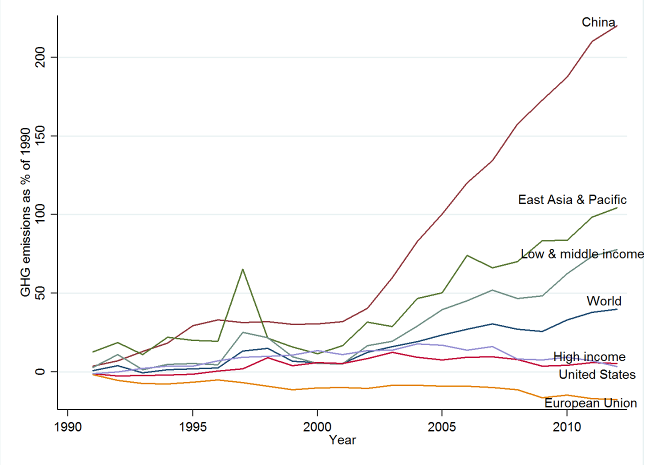
fective non-compliance measures set. According to the protocol, in the cases of non-compliance the non-complying party will face a deduction in the next commitment period equivalent to 1.3 times the amount of the violation. It may also be prevented from participating in the market based mechanisms provided by the protocol. However, for this penalty to be applied it needs the consent of the noncomplying party, and that's one of the reasons why these measure are weak [Böhringer, 2003]. Furthermore, these measures do not present themselves as sufficient incentives to encourage compliance unlike some other protocols –such as the Montreal protocol[10] - that uses trade sanctions on violating parties [Sunstein, 2007]. Additionally, the first commitment period of the protocol was set to be 5 years 2008-2012, which given the nature of the climate problem is not enough [Aldy and Stavins, 2008], especially since carbon dioxide and other GHG tend to remain in the atmosphere for decades. While this period may participation, it was a major disincentive when it comes to investment decisions of technological nature such as investment in cleaner technology or renwable energy facilities [Barrett, 1998].

2.3 Hypothesis

Current evidence of global emission shows that there is an increasing trend in emission levels. This seems to be in line with the expectations of the protocol's opponents. As shown in figure 1 the global GHG emissions are increasing relative to 1990 levels and they are driven mainly by the emissions of the developing world and in specific the Asian countries. On the other hand, the emissions of the EU exhibit a negative trend and the high-income countries emissions are stable.

[10]Montreal protocol aimed at reducing ozone depleting substances and is considered to be one of the effective international agreements targeting air pollution

Figure 1: The GHG emissions as % of 1990 emission levels



This provides evidence that the criticism of the protocol on the grounds of it being not sufficiently inclusive was valid and that leakage might have been a prominent problem. However, a simple comparison between the emissions of the countries legally bound by the protocol (EU countries) and the rest of the world's emissions shows that the protocol might have a reduction effect on emission levels of those countries. To examine the protocol's effectiveness more fairly it would be better to compare between the current GHG emissions and the current emissions with the expected business as usual (BAU) emissions that would have occurred in the absence of the protocol.

Based on the protocol's characteristics and despite the criticism addressed towards its effectiveness; the hypothesis proposed in this paper is that the protocol's effectiveness might lie mainly in its prevention of further harm than actual reduction of the emissions level. It might be the case that the Kyoto protocol was not a complete failure and was effective in reducing the emissions below what the BAU emissions that would have taken place if the protocol hasn't been in the picture. Especially given that 28 of the 36 countries bound by the protocol have actually managed to reach their targets, and even some countries managed to achieve more ambitious reductions and lowered their emissions levels below their targets (didn't use their whole Assigned amounts).

H: The ratification of Kyoto protocol led to lower emissions in industrialized countries than the expected BAU emission level.

3 Empirical strategy

3.1 Data

The dataset consists of 153 countries, 34 treated countries and 119 control countries. Out of the 36 parties in Annex B that originally ratified the protocol, only 34 countries are used due to the limited data availability of the remaining 2 countries Monaco and Liechtenstein. The data covers 18 years from the period 1995 till 2012. The treatment period is 2005 for all of the 34 parties except Australia as it ratified the protocol in 2007. The treatment period was set to be 2005 (enforcement period) rather than 2008 (commitment period) for several reasons. First, by 2005 most of the industrialized countries had ratified the protocol and given that the enforcement period is closer to the period of ratification, which is a process that involves the voters and politicians as well as domestic policy adjustments and hence essentially binds the policy makers to the protocol, it is more feasible to choose 2005 as the treatment period [Aichele and Felbermayr, 2012; Grunewald and Martinez-Zarzoso, 2016]. This is also in line with previous empirical studies on Montreal Protocol as well as the Helsinki protocol (part of LRTAP) that show that parties started adopting policies that aim at reducing their emissions before enforcements period commenced [Murdoch and Sandler, 1997; Ringquist and Kostadinova, 2005]. Second, long-lived gases like the GHG remain in the atmosphere for a while, Carbon dioxide can remain in the atmosphere for decades, and the emissions accumulate and hence the earlier a country reduces its emissions, the easier it will be for them in later years to maintain lower emission levels, especially given the that the Kyoto reduction targets are expected to be reached by the end of the 1st period- 2012- and not annually [Barrett, 1998]. Third, using the enforcement period will facilitate the comparison between the results estimated by the GSC method and those found in previous literature.

The output variable used is GHG excluding land use and forestry (in natural logarithm) from CAIT Climate Data Explorer 2015 provided by World Resources Institute. The CAIT provides data on the historical emissions of 6 major GHGs for 185 countries and the EU for the period 1990-2012 [11]. To ensure completeness and accuracy of the datasets, the WRI complements the

[11] For the countries that had change in their borders over the past years, the CAIT uses a consistent methodology to estimate previous emission levels based on the emissions in the 5 years after the formation (in the

data provided by the UNFCCC by compiling data from research center, government agencies and non-governmental sources (CAIT Climate Data Explorer, 2015). The reason for using GHG gases without the inclusion of land use and forestry is to have a clearer picture of the protocol's effect on the GHG reduction without the inclusion of sinks, as it has been one of the criticisms provided by the opponents of the protocol.

The control variables are used so as to account for the different emitting behavior across countries and were chosen following previous literature that addresses the effectiveness of environmental agreements [Bennear and Coglianese, 2005; Morley, 2012; Vollenweider, 2013; Grunewald and Martinez-Zarzoso, 2016; Almer and Winkler, 2017]. [12]. Three control variables are used. First, the real GDP per capita is used to account for the productivity of a country. Second, based on the Grossman and Kreuger findings, the squared real GDP per capita is used to capture the non-linear relationship between the GHG emissions and the income per capita. Third, the population size is used as proxy for the emitting behavior of the country in terms of consumption [Grunewald and Martinez-Zarzoso, 2016]. The control variables are from the World Bank's World development indicators transformed into their natural logarithm form.

3.2 Generalized synthetic control method

3.2.1 Why the GSC method?

The GSC method is used for causal inference using time-series cross-sectional data. It is used in this paper to estimate the effect of the Kyoto protocol on the emissions of industrialized countries by formulating a counter-factual from the control group. This counter-factual is formulated in a way such that it behaves very similarly (in terms of emissions) to the industrialized countries so that a comparison of performance post treatment could accurately reflect the effect of the treatment. In this sense the GSC is similar to the idea of the SCM by Abadie et al. [2010] to formulate a counter-factual unit by using information from the non-treated group of

case of separation such as ex-soviet union countries) of those countries. As for the unification cases (such as Germany) the methodology is more simple, where the emissions are simply added to each other

[12]Mainly based on the paper by [Grossman and Kreuger, 1995] 'Economic Growth and the environment'; where the growth of income was shown to have a significantly negative effect on air pollution levels as long as this income is below $8000 (1985 dollars) if the income is more than that, their results do not show a significant negative relationship between the income growth and air quality

units (control group). What the GSC adds is that it unifies the SCM with interactive fixed effects model. It computes the synthetic counter-factual semi-parametrically. It formulates it based on a linear interactive fixed effects (IFE) model that interacts unit specific intercept with time varying coefficients in 3 steps.

It has several attributes that make it preferable to other methods such as SCM and the D-I-D that could have been used in analyzing the Kyoto protocol as has been done in previous literature. The GSC adds to the SCM the possibility of having several treated units and different treatment periods, which is one of the main reasons why it is preferred over the SCM in this paper; given that there treated group consists of the 36 industrialized countries mentioned in Annex B in the protocol. Second, it improves the efficiency of the SCM and enhances the interpretability of SCM as it provides uncertainty estimates such as standard errors and confidence intervals, which makes the results easier to understand. Furthermore it conducts dimension reductions before the reweighting scheme so that the vectors reweighted are smoother over time. Third, the GSC estimator has a cross validation procedure built in that given sufficient data automatically selects the correct number of factors of the IFE model reducing the risk of over-fitting [Xu, 2017].

As for the D-I-D, the GSC method surpasses it in the case where the assumption of the parallel trends between the treated and control units in absence of treatment doesn't hold, like in the case of the presence of unobserved time varying confounders, which is the case here. There are some variables that can affect the emissions levels of a country such as the growth levels, population size, the dependence on the industry or agriculture sector as well as other variables that are not observed that may affect the treated unit and not the controls and vice versa. Hence, in this case we cannot assume that the industrialized (treated) countries and the control group follow same trends. The GSC method addresses the lack of parallel trends between control and treated units, as it models the unobservable time-varying coefficients semi parametrically by using the interactive fixed effects model proposed in Bai [2009]. In addition to that it corrects the bias of the interactive fixed effects (IFE) model when the treatment effects are heterogeneous across units, which is sometimes the case with the GHG emissions trends across industrialized countries.

In general the GSC method has 3 main limitations. The first limitation is that the estimates may be biased if the pre-treatment period or the number of control units are small, to be specific a pretreatment period less than 10 years or number of control units less than 40 unit. This does not pose as a problem as the control group used here is 119 country and the pretreatment period is not less than 10 years.

A second limitation is that it cannot handle complex data generation procedure (DGP); either in terms of presence of structural breaks, or the presence of a dynamic relationship between the treatment and the outcome variable (such as the case of a lagged dependent variable) or different treatment intensities and multiple treatment periods. The data used is annual GHG emissions, the treatment period is either 2005 or 2007 and the treatment intensity should not be very different (at least theoretically). Accordingly the DGP should not be complex.

A third limitation is that the model specification play an important part here unlike the SCM, where the procedure would not run if those specifications are not met, the GSC method would generate results, however, they might be biased if the treated and control units do not share the same factor loadings and would lead to excessive extrapolation. This problem-if it exists can be detected when looking at the plot of the factor loadings of the treated and control group, where the plot of treated units would deviate from the plot of the control units [13].

3.2.2 Framework

Following the frameworks previously used in causal inference, in the GSC Xu [2017] uses the same notations to denote the outcome of a certain unit i at time t by Y_it. Based on the first assumption of the GSC method, that the treated and control units have to be affected by the same set of factors with no structural breaks in the observed time period, the outcome of unit i at time t is expressed as

$$Y_{it} = \delta_{it} D_{it} + X'_{it}\beta + \lambda'_i f_t + \epsilon_{it} \tag{1}$$

where D_{it} takes the value of 1 in the case that unit i at time t was legally bound by the Kyoto protocol. Accordingly δ_{it} is the effect the protocol on unit i at time t. X is a (k $\times$ 1) vector of

[13] The plot of the loadings of the treated group should lie in the convex hull of the control group

observed covariates and β is a (k $\times$ 1) vector of unknown parameters. f is an (r $\times$ 1) vector of unobserved common factors representing the time varying coefficients and λ_i is an (r $\times$ 1) vector of factor loadings representing country specific intercepts. ϵ_{it} is the error term and has a mean of zero.

Based on the abovementioned functional form, the treatment effect would then be represented by the difference between $Y_{it}(1)$ and $Y_{it}(0)$, in which $Y_{it}(1)$ represents the outcome of treated unit i at time t where $D_{it} = 1$ and $Y_{it}(0)$ is the outcome of control unit i at time t. This treatment effect is captured by

$$\delta_{it} = Y_{it}(1) - Y_{it}(0), \qquad t > T_0 \tag{2}$$

The counter-factual is formulated from the pool of control units in this case the group of countries that did not have legally binding targets in the protocol, so the outcome of a unit from the control group at time t can be expressed in the following equation

$$Y_{it} = X'_{it}\beta + \lambda'_i f_t + \epsilon_{it}$$

and hence combining all controls together the outcome of the counterfactual is

$$Y_{co} = X'_{co}\beta + F\Lambda'_{co} + \epsilon_{co} \tag{3}$$

where Y_{co} is a (T$\times$ N_{co}) matrix,X_{co} is a three dimensional matrix (T$\times$ N_{co} $\times$ p) and Λ_{co} is (N_{co} $\times$ r) and $X'_{co}\beta$,F Λ'_{co} and ϵ_{co} are (T $\times$ N_{co}) matrices. β , F and Δ_{co} are constrained by 2 constraints to be able to identify them; first that all factors are normalized and second they are orthogonal to each other. The main aim of the GSC is to find the effect of the treatment by finding the average difference between the treated unit(s) and its counter-factual. This difference can be expressed by the following equation

$$ATT_{(t,t>T_0)} = \frac{1}{N_{tr}} \sum_{i \in \tau} [Y_{it}(1) - Y_{it}(0)] = \frac{1}{N_{tr}} \sum_{i \in \tau} \delta_{it} \tag{4}$$

to be able to compute the treatment effect in equation 2 and then 4, the counte-rfactual unit is estimated by the GSC in 3 steps.

3.2.3 Formulation of Counter-factual

The general idea is to choose the model that leads to the most accurate predictions, so to be able to find this model some of the data is withheld (a small part) and the remaining part of the data is used to make predictions for the withheld part and the model that provides the most accurate predictions is the chosen model. The 1st step is to obtain a fixed number of latent factors by estimating an IFE model using control group data

$$(\hat{\beta}, \hat{F}, \hat{\Lambda_{co}}) = \underset{\hat{\beta}, \hat{F}, \hat{\Lambda_{co}}}{\operatorname{argmin}} \sum_{i \in \tau} (\tilde{Y}_i - \tilde{X}_i \beta - \tilde{F} \tilde{\lambda}_i)' (\tilde{Y}_i - \tilde{X}_i \beta - \tilde{F} \tilde{\lambda}_i)$$

$$s.t. \frac{\tilde{F}' \tilde{F}}{T} = I_r \ and \ (\tilde{\Lambda'_{co}} \tilde{\Lambda_{co}})$$

The second step is to estimate the factor loadings $\hat{\lambda}_i$ (unit specific intercepts) by projecting pretreatment outcomes of the treated units(s) on the space spanned by the factors estimated in the 1st step

$$\hat{\lambda}_i = \underset{\hat{\Lambda}_i}{\operatorname{argmin}} (Y_i^0 - X_i^0 \hat{\beta} - \hat{F^0} \tilde{\lambda}_i)' (Y_i^0 - X_i^0 \hat{\beta} - \hat{F^0} \tilde{\lambda}_i)$$

$$= (\hat{F^0}' \hat{F^0})^{-1} \hat{F^0}' (\hat{Y^0} - \hat{X_i^0} \hat{\beta}), \quad i \in \tau$$

The 3rd step is to estimate counter-factual based on factor and factor loadings computed in step 1 and 2

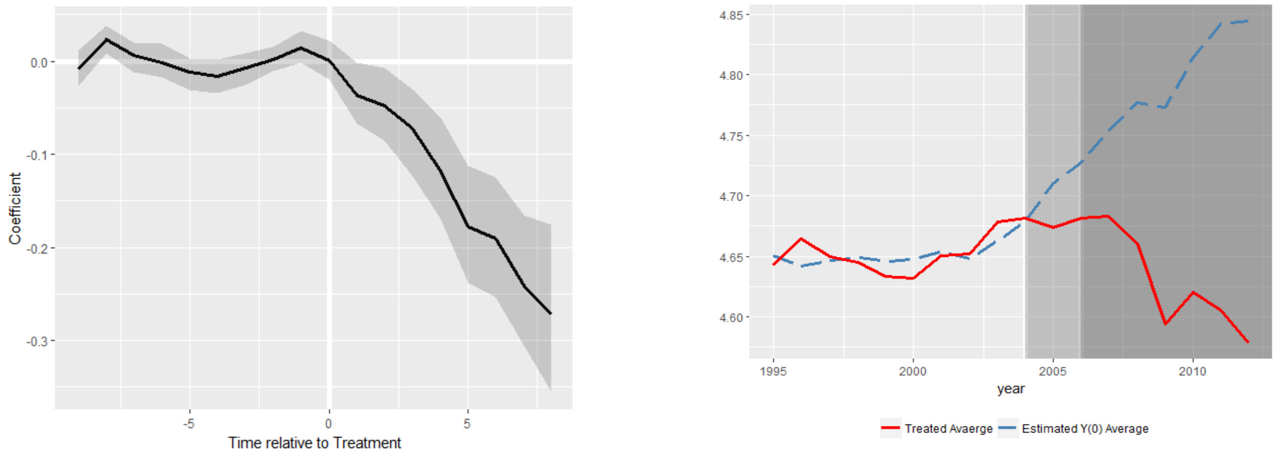
$$\hat{Y_{it}}(0) = x'_{it} \hat{\beta} + \hat{\lambda_i}' \hat{f_t}, \qquad i \in \tau, t > T_0$$

4 Results

4.1 Main results

The results show that the Kyoto protocol has been successful in reducing the GHG emissions of the industrialized countries, even with the exclusion of sinks, when compared to the counterfactual representing BAU scenario.

Figure 2: The estimated treatment effect on the industrialized countries



(a) Gap between counterfactual and treated

(b) Emissions of treated and counterfactual

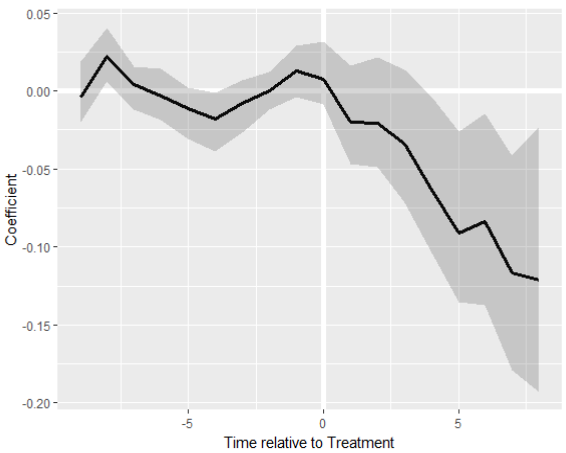
As shown in figure 2, the emissions of the treated group are declining. In Figure 2 a, which represents the gap between the counterfactual (horizontal line) and the treated group emissions, it is clear that the treated group have declining emission rates after the treatment period (the zero vertical line). Figure 2 b shows that the counterfactual representing the expected BAU levels (the dashed line) has higher emissions in comparison with the actual emissions of the treated group (represented by the solid line). The cross validation scheme found 1 unobservable factor[14] to be important, so the average treatment effect on the treated countries (ATT) based on the estimations of the GSC method after conditioning on the additive fixed effects and the unobservable factors is a reduction of approximately 14.3%. When including the predictor variables to account for the differences of emission behavior between the countries (figure 3), the cross validation scheme found 1 unobservable factor and the ATT is estimated to be more conservative with an approximate 6.8% reduction. Both results are significant as shown in the parentheses in table 1.

[14]Based on Xu [2017] the unobservable factors found are not directly interpretable. In this case (it is 1 factor) it may simply refer to a time trend that has a heterogeneous effect on the different unit

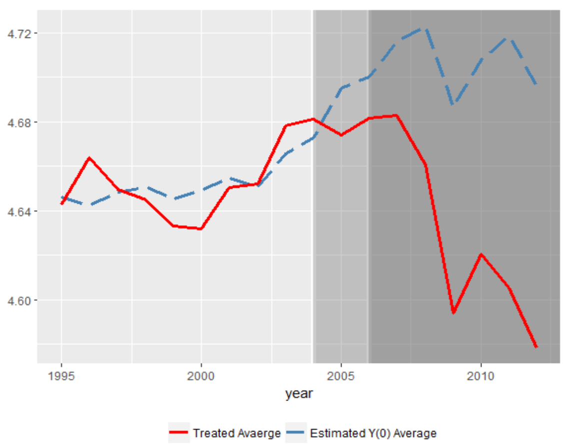
Table 1: Effect of Kyoto protocol on GHG emissions (excluding LUCF)

	Treatment only	Including controls
Variable	*ATT*	*ATT* / ***Beta coefficient***
Ln GHG (excluding LUCF)	-0.143	-0.0684
	(0.000)	(0.016)
Ln Real GDP per capita		-5047.9
		(0.644)
Ln (real GDP per capita) squared		2524.15
		(0.644)
Ln population		0.730
		(0.000)
MSPE	0.00204	0.00159
Unobserved factors	1	1
Treated units	34	
Control units	119	

Figure 3: The estimated treatment effect on the industrialized countries (using controls)



(a) Gap between counterfactual and treated



(b) Emissions of treated and counterfactual

In other words, the results provide evidence that the protocol has managed to succeed in reducing the emissions of the industrialized countries that ratified the protocol. The estimated reduction is approximately 14.3% less than their expected BAU emissions that would have occurred in the case that the protocol had not provided strict obligations and targets to be achieved for the industrialized countries to reduce their emissions. After controlling for different emitting behavior, the results show a more conservative yet non-negligible reduction of 6.8% in the emissions of the treated countries as compared to the expected emissions in "no-Kyoto" scenario.

It's worth mentioning that when controlling for the emitting behavior of the countries the gap between the treated group's emissions and the counterfactual seems to lessen by the end of the period as shown in figure 3. This could be interpreted in 2 different ways, either that the countries by the end of the commitment period increased their emissions or that these countries would have sooner or later reduced their emissions by 2012 disregarding the protocols binding targets. However, looking at figure 3b, which illustrates the emissions of both the treated group (solid line) and the control countries (dashed line) it seems that the second interpretation is more fitting as the counterfactual's emissions seems to be declining. To clarify, the results should not be mistakenly interpreted that the GHG of the industrialized countries have shrunk by 6.8% than their pretreatment emissions, rather- as represented in figure 3- it represents a reduction compared to the emissions that were expected to take place given the protocol had not set target emissions for these countries.

4.2 Robustness checks

4.2.1 Potential Endogeneity: non-random treatment

One of the main challenges that face empirical studies on international agreements is endogeneity arising from self-selection into the agreement and the Kyoto protocol is no exception. The endogeneity in this case may arise from the fact that the countries that are legally bound by a target level were chosen by the UNFCCC based on their previous industrialization, so the treatment is not random. In addition to that not all those countries mentioned in Annex B ratified the protocol, so self-selection is a probable issue. The use of the synthetic counterfactual reduces the bias as the unobservable confounders that may cause endogeneity should- at least theoretically- affect the counter-factual as well since it formulates a synthetic country that is almost identical to the treated one, so if the treated countries had a high emission level previously then the counter-factual should as well had the same level[Billmeier and Nannicini, 2013], however, it does not eliminate it completely. The unobservable confounders found by the GSC estimators should also alleviate the concern for endogeneity [15] as it should capture

[15] Xu provides a detailed explanation for how the GSC estimator should alleviate concerns for endogeneity in section 5 in his paper

Table 2: Effect of Kyoto protocol on GHG emissions including predicted treatment

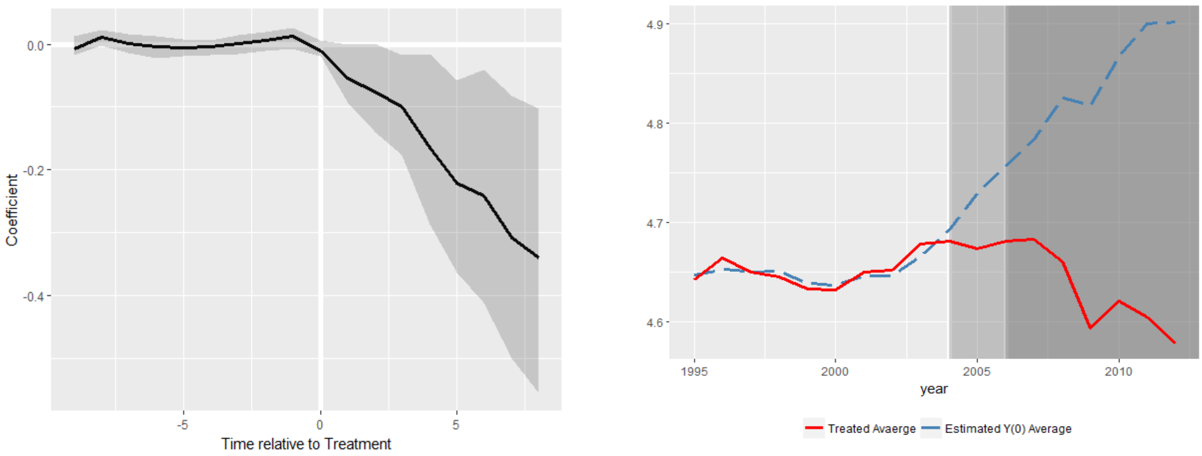
	Treatment only	Including controls
Variable	*ATT*	*ATT* /***Beta coefficient***
Ln GHG (excluding LUCF)	-0.187	-0.065
	(0.004)	(0.012)
Ln Real GDP per capita		-8.376e+03
		(0.856)
Ln (real GDP per capita) squared		4.188e +03
		(0.856)
Ln population		8.811e-01
		(0.000)
Predicted treatment	0.0054	1.140e -02
	(0.292)	(0.048)
MSPE	0.00151	0.00162
Unobserved factors	2	1
Treated units	34	
Control units	95	

the inherent differences that could result from the treatment being non-random and since the GSC estimator takes the unobservable confounders found into account when formulating the counter-factual, the concern for endogenity should be eased [Xu, 2017].

Nonetheless, to ensure the robustness of the results, the potential endogeneity is addressed. To do so, the industrialization factor should be taken into consideration as it is the base on which countries were chosen by the UNFCCC to be legally bound by the emission reduction targets. To account for the industrialization effect on the ratification of Annex B countries a probit regression (eq.5) is run to get the predicted propensity to ratify the protocol based on the division of the country's GDP (in terms of value added of different sectors), growth rate and emissions levels, and use the predicted value as a control variable in the GSC method. The predicted propensity to ratify is imputed based on the model's estimation and used as one of the predictor variables in the GSC estimator to account for the endogeneity. The results of the GSC estimator after the inclusion of the predicted treatment are the same. The ATT is predicted to be a reduction of approximately of 18% which is even higher than the estimated effect in the main results. However, when including control the effect is approximately 6.5% compared to the counterfactual's emissions (shown in table 4), which is the same estimated effect as the previous estimation (shown in table 1).

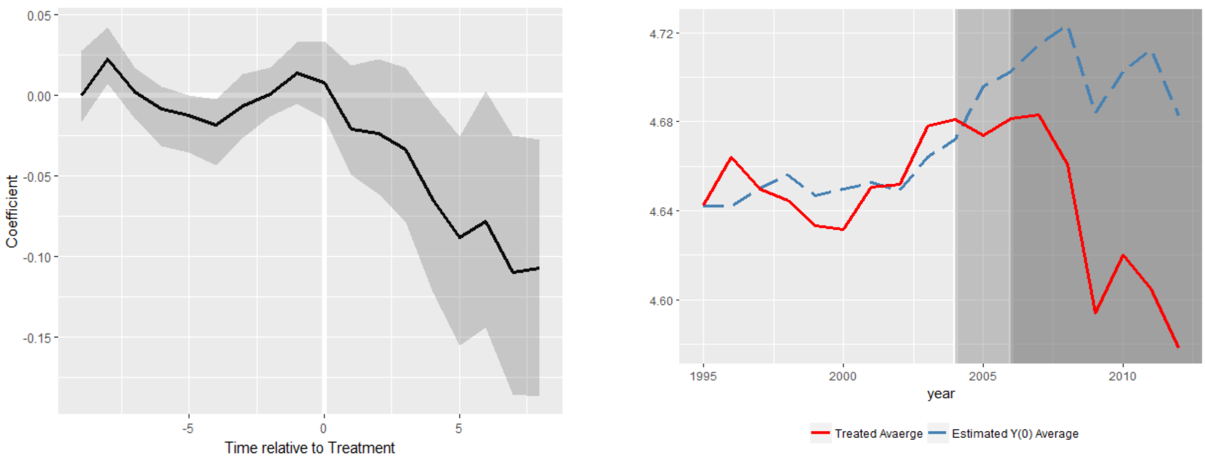
The estimated counterfactual shown in figure 6 and 7 is also very similar to the ones estimated in the previous model and illustrated by figure 2 and 3. The similar, almost equivalent-treatment effects in the 2 models, adds to the robustness of the estimated counterfactual and provides evidence that the non-random selection of treatment did not prove to bias the estimated treatment effects.

Figure 4: The estimated treatment effect on the industrialized countries



(a) Gap between counterfactual and treated (b) Emissions of treated and counterfactual

Figure 5: The estimated treatment effect on industrialized countries (controlling for emission behavior)

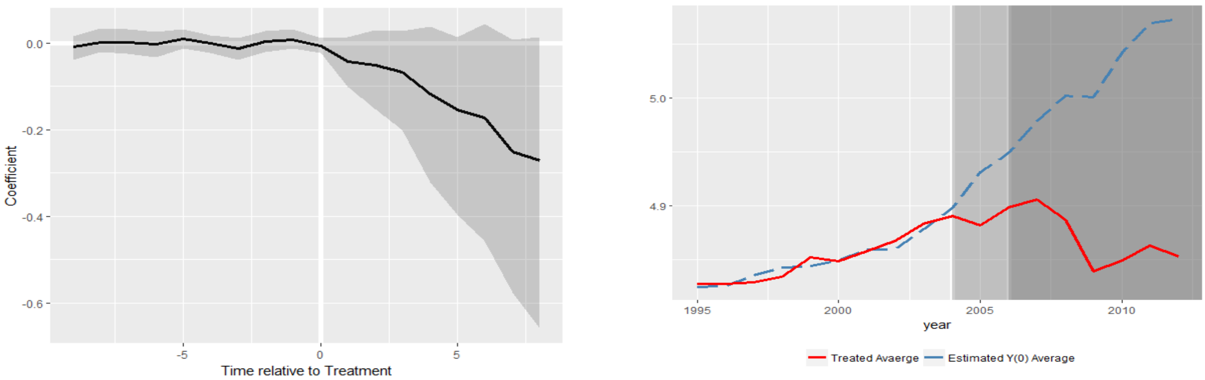


(a) Gap between counterfactual and treated (b) Emissions of treated and counterfactual

4.2.2 The European Union

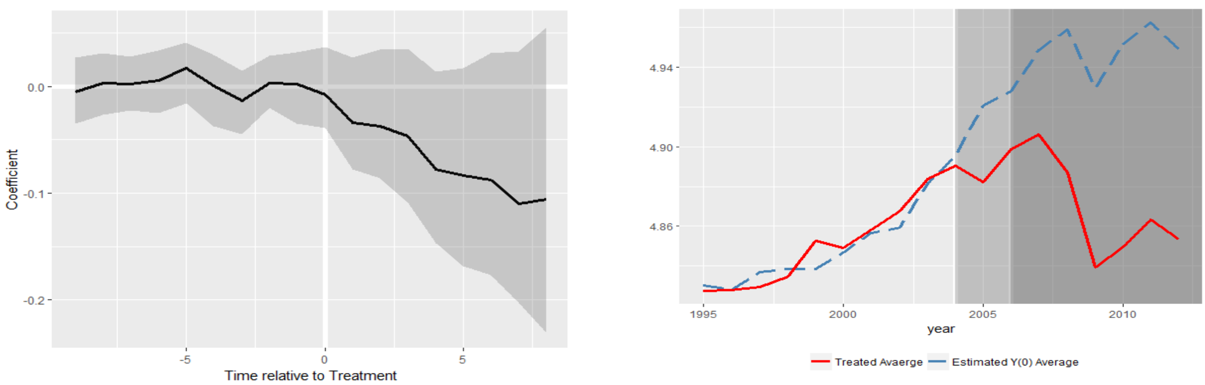
The European community represents a large group of the industrialized countries and as a union they have other agreements such as the "Long-run Trans-boundary Air Pollution" (LRTAP) and its protocols as well as directives such as the "Air quality framework" directive in 1997, the "New air quality" directive that govern and regulate air pollution and harmful gas emissions. As a consequence, the incentives presented to the EU to reduce their emissions and shift to cleaner technology is higher than other countries, even if the gases focused on in these agreements are not necessarily the same. So in order separate the Kyoto effect, the European community was removed from the treated group and a new counterfactual is formed for the industrialized non-EU countries.

Figure 6: The estimated treatment effect on the non-EU industrialized countries



(a) Gap between counterfactual and treated (b) Emissions of treated and counterfactual

Figure 7: The estimated treatment effect on the non EU industrialized countries (controlling for emission behavior)



(a) Gap between counterfactual and treated (b) Emissions of treated and counterfactual

The results –presented in figures 4 and 5 as well as in table 2 - show that when the EU countries were removed from the treated group, the protocol still has a negative significant effect on the industrialized countries emissions. In the case of testing the effect of the treatment only

Table 3: Effect of Kyoto protocol on GHG emissions (excluding LUCF)

	Treatment only	**Including controls**
Variable	*ATT*	*ATT* /***Beta coefficient***
Ln GHG (excluding LUCF)	-0.137	-0.071
	(0.064)	(0.096)
Ln Real GDP per capita		-5047.92
		(0.656)
Ln (real GDP per capita) squared		2524.15
		(0.656)
Ln population		0.7306
		(0.000)
MSPE	0.00124	0.00100
Unobserved factors	2	1
Treated units	9	
Control units	119	

(with no control variables), the approximated reduction is more or less unchanged; around 13.7% as compared to 14.3%. When controlling for the emission behavior of the countries the reduction is a significant 7% reduction approximately as compared to approximately 6.8% reduction that was estimated when the European community was included in the treated group. The results show that the removal of the EU didn't have a difference on the magnitude of the effect of the protocol"s effectiveness.

The results may seem counter intuitive at first glance, as this would deem the regional regulation in the EU ineffective. However, within the EU there are several former soviet union (FSU) countries that were assigned 'Hot-Air' and accordingly had the right to increase emissions without violating the protocol"s obligations, which may explain the less than expected reduction in the EU.

4.2.3 Hot Air

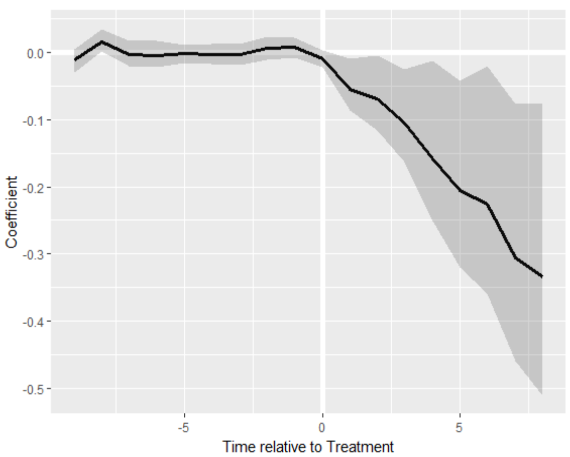
One of the main criticisms of the Kyoto protocol is what is known as 'Hot Air'. 'Hot Air' refers to the assigned amounts of emissions of FSU countries that exceeded their expected BAU emissions levels. The main concern with the so-called 'Hot air' is that it may bias the results by deflating the reduction attributed to the protocol, as the FSU countries didn't have an obligation to reduce their emissions. Hence computing the average treatment effect while including them in the treated group would show a reduced treatment effect In order to overcome

Table 4: Effect of Kyoto protocol on GHG emissions excluding FSU

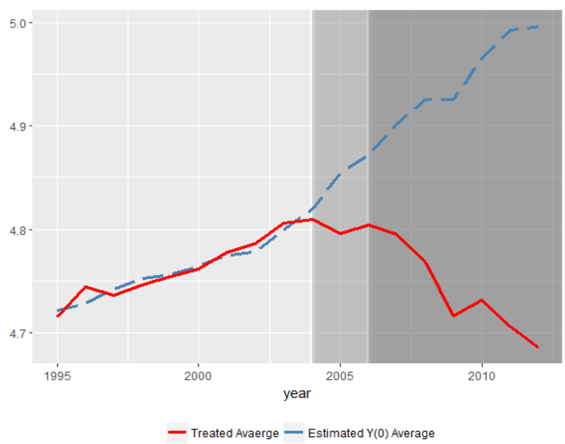
	Treatment only	Including controls
Variable	*ATT*	*ATT* / ***Beta coefficient***
Ln GHG (excluding LUCF)	-0.180	-0.172
	(0.052)	(0.052)
Ln Real GDP per capita		1.005944e +04
		(0.856)
Ln (real GDP per capita) squared		-5.029559e +03
		(0.480)
Ln population		7.008992e-02
		(0.480)
MSPE	0.00192	0.00174
Unobserved factors	2	2
Treated units	22	
Control units	119	

this possible bias, the FSU countries were removed from the treated group so as to analyze the "net" effects of the protocol. Results show that removing the FSU countries from the treated group increased the magnitude of reduction to be 17% rather than the approximate 7% shown in previous results. This goes in line with the intuition that the extra assignments of emission units have motivated and increase in these countries' emissions or at the very least did not motivate any reduction of emission levels. It may also explain why the EU reductions as a group were undermined, as some of the FSU countries joined the EU.

Figure 8: The estimated treatment effect on the industrialized countries excluding FSU countries

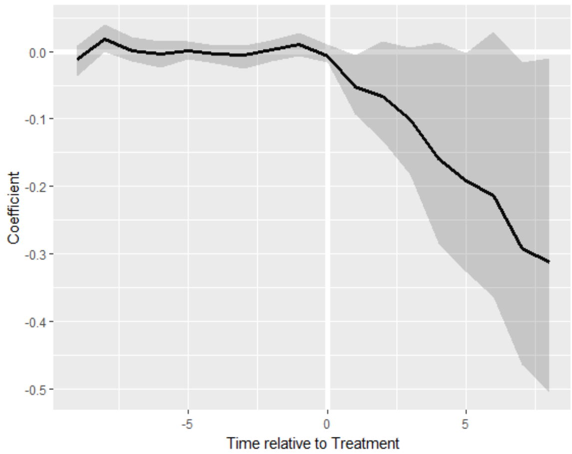


(a) Gap between counterfactual and treated

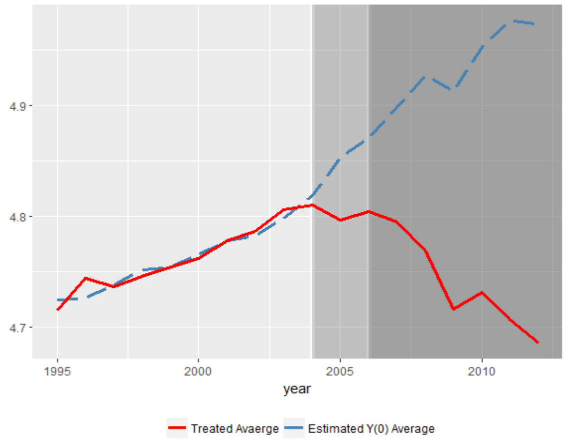


(b) Emissions of treated and counterfactual

Figure 9: The estimated treatment effect on industrialized countries excluding FSU countries (controlling for emission behavior)



(a) Gap between counterfactual and treated



(b) Emissions of treated and counterfactual

5 Conclusion

International environmental agreements have been increasing in number over the past decades and so have the controversy surrounding their effectiveness. Even though IEAs face several obstacles especially those tackling public goods such as the agreements tackling climate change, the world has been witnessing an increase in their number still. However, whether the increase in number of agreements is a positive and effective thing is a question that has been and still is subject of great controversy among politicians, lawyers and scientists.

The aim of this paper was to test one of the most ambitious agreements tackling climate change problems, namely the Kyoto protocol, to find out whether these agreements add value in terms of environmental preservation. By using the generalized synthetic control (GSC) method the emissions of the industrialized countries after ratification were compared with a synthetic counterfactual that represents a hypothetical scenario of the would-have-been emissions in the case of non-ratification. The results show that the industrialized countries that ratified the protocol had at least an approximate of 7% reduction in their emissions as compared to their expected emissions if they had proceeded without the protocol's targets in mind. Removing the European Union from the group showed no difference in the reduction effects. However, the removal of the FSU countries showed an increase in the magnitude of the reduction, which is mainly attributed to their assignment of hot air.

Even if the protocol has not achieved its entire targets and more importantly the fight against global warming still persists, it still was a successful first step that at least-based on the results provided in this paper- prevented a worse emission level from taking place. Further steps are needed of course and this is realized by the global community as shown by the agreements that took place and are still taking place after the Kyoto protocol's commitment period ended. This also means that hope for the Paris agreement should not be lost after the de-ratification of the US. As was shown in the case of the Kyoto protocol, the non-participation of some countries such as the US, did not render the treaty useless.

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A Probit model

The probit is presented in the following equation:

$$Treat_i = \alpha + \beta_1 Ind_i + \beta_2 Trade_i + \beta_3 Srvc_i + \beta_4 Agrclt_i + \beta_5 GDPgr_i + \beta_6 GHG_i + \epsilon_i \qquad (5)$$

Where $Treat_i$ is a binary variable that takes 1 if country i is in Annex B and ratified the Kyoto protocol and zero otherwise, Industry represents the value added of Industry in % of GDP, $Trade$ is a the trade openness presented in % of GDP, $Srvc$ is the value added of service as % of GDP, $Agrclt$ is the value added of agriculture as % of GDP, $GDPgr$ is the annual growth rate of the GDP per capita and GHG represent the greenhouse gas emissions excluding LUCF. The model is highly significant and the results of the probit regression are shown in table 3.

Variable	**Coefficient**	**Std. Err.**	**z**	**P>z**	**95% Conf.**	**Interval**
Dependent	**Variable**	***Propensity***	***to***	***ratify***		
Ind	.2395032	.2140551	1.12	0.26	-.1800372	.6590435
Trade	-.0026495	.0007259	-3.65	0.000	-.0040723	-.0012268
Srvc	.2781204	.2138152	1.30	0.193	-.1409497	.6971906
Agrclt	.0937622	.2131269	0.44	0.660	-.3239589	.5114834
GDP growth	.0187825	.0092052	2.04	0.041	.0007406	.0368244
lagged GHG	-.0002217	.0000488	-4.54	0.000	-.0003173	-.000126
constant	-25.52209	21.38154	-1.19	0.233	-67.42913	16.38495

Table 5: Probit Model Resutlt