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The Effect of Kyoto Emission Targets on Domestic CO_2 Emissions: A Synthetic Control Approach*

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Abstract: We use recent developments in the empirics of comparative case studies to analyze the effect of binding emission targets under the Kyoto Protocol on the development of CO_2 emissions of seven major Annex B countries. In particular, we investigate whether committing to a specific greenhouse gas emissions target had an effect on actual CO_2 emissions of Australia, Canada, France, Germany, Great Britain, Italy and Japan by using a synthetic control approach. With the exception of Great Britain, we are not able to reject the hypothesis that there has been no effect of binding emission targets on actual emissions.

Keywords: Climate Policy, International Environmental Agreements, Kyoto Protocol, Synthetic Control Method

JEL-Classification: K33, Q54

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1 Introduction

The international community persistently fails to agree on a uniform climate policy succeeding the Kyoto Protocol (KP).[1] This has already become apparent during the climate conferences in Copenhagen and Cancún in December 2009 and 2010. The last meeting in Durban in December 2011 reiterates the two major impediments: First, emerging economies, such as India and China, are not willing to commit to emission reduction targets in the near future. Second, some industrialized countries (e.g., Canada, Japan, and Russia) are no longer willing to accept restrictions on their greenhouse gas (GHG) emissions. In spite of these obstacles, a renewal of the KP is considered as one of the few solutions with at least modest chances to gain sufficient international support. However, it is not clear whether a continuation of the KP – even if extended to include countries in transition such as China, India or Brazil – is such a good idea. The key question one might ask before considering a particular agreement to be prolonged or extended is whether and to what degree it has been successful.

In this paper, we analyze whether the KP has lived up to its primary goal, the reduction of GHG emissions in the industrialized world. We test for the existence of observable domestic emissions reduction efforts in seven major Annex B countries. The main obstacle to analyzing the effect of the KP on the emissions of Annex B countries is the identification of the correct counterfactual business-as-usual (BAU) emissions to which the actual GHG emissions have to be compared. We construct BAU emission paths by employing a synthetic control approach, as introduced by Abadie and Gardeazabal (2003) and Abadie et al. (2010). In this approach, the counterfactual for each "treated" country (i.e., Annex B countries that ratified the KP and, thus, are subject to GHG emissions targets) is constructed by a weighted average of "non-treated" countries (i.e., all countries without binding emission targets under the KP) such that the actual country and its synthetic counterpart coincide as much as possible with respect to emissions before the "treatment" (adoption of the KP) and in all relevant characteristics that are unaffected by it. The difference of the emission paths of the actual country and its synthetic counterpart following the treatment reveals the influence the binding emission targets of the KP imposed on the development of domestic GHG emissions.

In our analysis we focus on seven major GHG emitters with binding GHG emission targets under the KP, namely Australia, Canada, France, Great Britain, Germany, Italy

[1] In the KP the industrialized countries of the world, so called Annex B countries, committed themselves to a reduction of greenhouse gas (GHG) emissions by 5.2% against 1990 levels over the period from 2008 to 2012.

and Japan. We only consider changes in *domestic* GHG emissions for two reasons. First, the KP explicitly obliges countries with binding emission targets to achieve their reduction goals primarily by domestic actions. Second, allowing for emissions trading among treated countries and between treated and non-treated countries via so-called flexibility mechanisms imposes insurmountable obstacles to eliciting the treatment effect of treated countries. While emissions trading among treated countries implies that the stable unit treatment value assumption (SUTVA) would be violated, emissions trading between treated and non-treated countries would blur the distinction between treated and non-treated countries.[2]

Among the seven countries under consideration, we only find a significant reduction of GHG emissions compared to BAU emissions for Great Britain. Further, we can rule out treatment effects for Australia, Canada, Italy and Japan. For France and Germany we find a treatment effect but our inference analysis renders these effects insignificant. These results are supported by the assessment of the "demonstrable progress reports", which all Annex B countries with binding emission targets under the KP had to compose in order to communicate their progress in reducing emissions until 2005. Thus, at least for the major polluters, we find little evidence for reduced emissions due to the KP.

Of course, we are not the first to challenge the KP. In fact, since its emergence in 1997 the KP has been heavily criticized. In December 1997 "The Economist" already prognosticated that the USA will never be able to ratify the KP, as it would never be approved by the U.S. Senate.[3] Prins and Rayner (2007) criticize its inflexible top-down architecture, which had been borrowed from past international treaties regulating chlorofluorocarbons, sulphur emissions and nuclear weapons, and "was always the wrong tool for the nature of the job." Also the economics profession found little praise for the KP. While Barrett (1998) argued from a political economy point of view that the KP hardly deters non-participation and non-compliance, Copeland and Taylor (2005) criticize that its design neglects important lessons from trade theory. Other authors animadvert the level of the emission targets (e.g., Tol 2000) or discuss the challenges of the flexibility mechanisms (Zhang and Wang 2011).

With respect to the analysis of the KP's capability of reducing domestic GHG emissions our paper is most closely related to Aichele and Felbermayr (2011). While they focus on

[2] Our restriction on domestic GHG emissions also excludes emissions contained in traded goods (not subject to regulation under the KP), which might overestimate the treatment effect. As a consequence, omission is at most a concern for countries exhibiting a significant treatment effect.

[3] The Economist (US edition): Global warming. Rubbing sleep from their eyes. Dec 11th 1997

the effect of the KP on the carbon footprint,[4] they also find a significant negative average effect of ratification on domestic CO_2 emissions. This result is somewhat at odds with our result that the KP had no significant effect on the CO_2 emissions of all countries under investigation apart from the UK. The opposing results may stem from employing different empirical techniques or defining a different treatment event. With respect to the former, the differences-in-differences approach employed by Aichele and Felbermayr elicits the *average* treatment effect on the treated (ATT) and their instrumental variable approach captures the average treatment effect for all countries (ATE) in their sample. In contrast, the synthetic control approach applied in this paper quantifies the treatment effect for each treated country individually. We focus on the individual analysis, as emission targets differ substantially among the treated countries (ranging from 72% for Luxembourg to 125% for Spain compared to their 1990 levels). As different targets may induce different effects on CO_2 emissions, treatment effects are most likely heterogenous and do not follow a common trend. With respect to the latter, Aichele and Felbermayr use ratification of the KP as the treatment period. In contrast, we employ the adoption of the KP in November 1997 as the time of treatment. We chose adoption, as at that time emission targets for Annex B countries were already known and, thus, could already have influenced countries GHG emissions.

The paper is organized as follows. In Section 2 we briefly summarize important facts about the design of the KP. We start the empirical analysis in Section 3 by reporting on the used data. We then contrast a classical differences-in-differences approach with the synthetic control method to estimate the effect of a binding emission target under the KP on the development of GHG emissions. The results are discussed in Section 4. Section 5 concludes.

2 Greenhouse Gas Emission Targets under the Kyoto Protocol

In the Kyoto Protocol (KP), initially adopted on 11 December 1997, 39 industrialized countries (and the European Community), so called Annex B countries, commit to reduce the emissions of four greenhouse gases (GHGs) by 5.2% on average over the period between 2008 to 2012 compared to 1990 levels. It was open for signature between 16 March 1998 and 15 March 1999. Over this period the KP received 84 signatures. Of the 39 countries with reduction commitments, only Belarus, Hungary and Iceland did not

[4] The carbon footprint of nations also accounts for emissions trading and for emissions through the import and export of goods.

sign the protocol (Belarus just joined the list of countries with reduction commitments in November 2006). In addition to signature, countries had to ratify the protocol in order to accede to it. Countries which did not sign the protocol during the signature period were able to join it by ratification at any time later on.

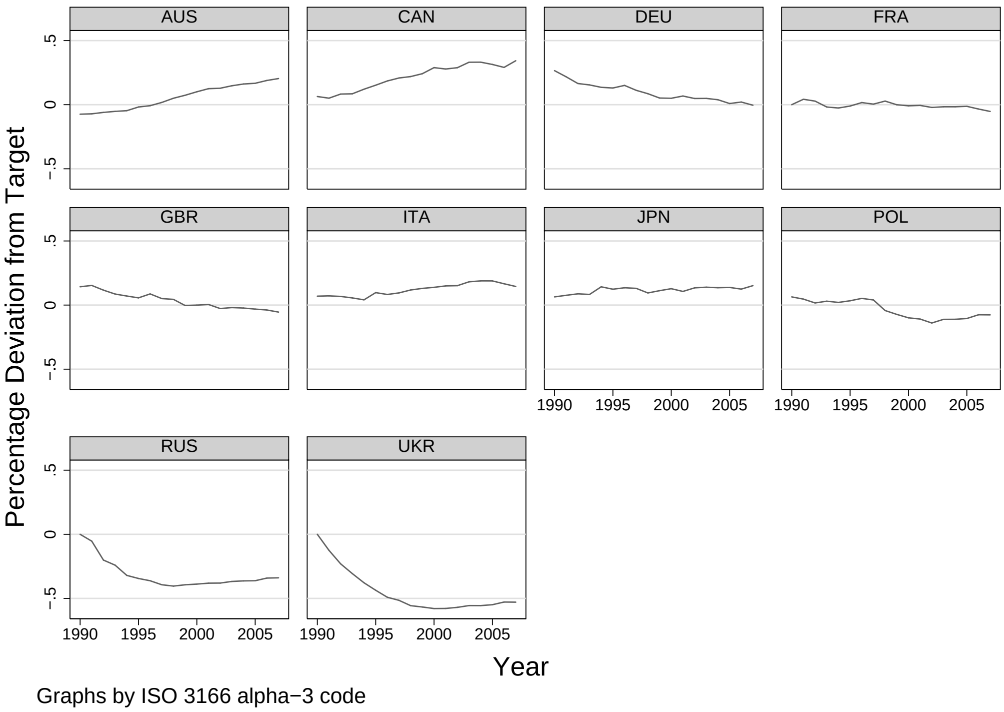
For all countries under investigation we consider the adoption of the KP in December 1997 as the treatment event in our analysis – irrespective of their date of signature or ratification. In fact, as the emission targets were already known in 1997, and with its adoption the KP took the first hurdle to become enacted, we consider 1997 as the earliest time at which the KP could have imposed a treatment effect.[5]

One might argue that in order to assess the effectiveness of the KP one would just have to look at countries' levels of compliance. As the commitment period ranges from 2008 to 2012, we yet lack final emissions data to assess the effectiveness of the KP with respect to compliance levels. However, plotting GHG emissions as relative deviation from the emission target over time for the ten largest GHG emitters facing emission targets under the KP, we observe that countries split into three distinct groups (see Figure 1): (i) there are countries which are already far below their emission targets (e.g., Russia and Ukraine), (ii) countries that are above their targets but converge towards them (e.g., Germany and Great Britain) and (iii) countries that are above their targets and further diverge from them (e.g., Australia and Canada).

We argue that the deviation from the emission targets is not a reliable indicator for the effectiveness of the KP with respect to emission reductions. The reason is that the business-as-usual (BAU) emissions – the GHG emissions that would have occurred without the adoption of the KP – were uncertain when the emission reduction targets were negotiated in 1997. Of course, these targets have been negotiated with expected BAU emission paths in mind, but expectations do not necessarily have to prove true. Moreover, expectations about BAU emissions may have been (almost) correct for some countries and at the same time (drastically) wrong for others. As an example, consider the countries within group (i). Countries in this group were predominantly members of the Former Soviet Union (FSU). After the collapse of the FSU, these countries experienced a severe economic downturn in the 1990s accompanied by a drastic decline in greenhouse gas emissions. In spite of later economic recovery, GHG emissions in all these countries are still far below their 1990 levels and they will definitely comply with their Kyoto targets. Thus, neither does the convergence of a country towards its emission target imply that it did a good job in reducing GHG emissions compared to its BAU emissions

[5] Of course, results would still be consistent if the treatment effect started later on.

Figure 1: Development of the deviation of greenhouse gas emissions relative to the Kyoto Protocol target in percent from 1990–2007 for Australia, Canada, Germany, France, Great Britain, Italy, Japan, Poland, Russia and Ukraine.



nor does the divergence of a country from its emission target indicate that the country did not significantly cut down GHG emissions compared to the BAU paths.

As a consequence, we need to assess the counterfactual GHG emissions that would have occurred if the KP would have not been adopted for each country with binding emission target under the KP and compare these to the actual GHG emissions. The resulting difference is a measure of the effectiveness of the KP in the sense that it indicates how much GHG emissions have been abated due to the adoption of binding emission targets within the framework of the KP. Thus, we consider the adoption of binding emission targets under the KP (contingent on later ratification) as a "treatment" and ask what was the effect of this treatment. To answer this question it is crucial that there are other countries which did not receive the treatment. In our case these are all the countries which do not have any binding obligations with respect to GHG emissions reductions under the KP. If all countries were equal in all respect apart from receiving the treatment or not, the treatment effect would simply be given by the difference in GHG emissions of treated and non-treated countries. Of course, not all countries are alike. Even worse, there is a clear selection bias with respect to the treatment: only Annex B countries – which roughly equals to the industrialized world – face a binding GHG emission target.[6] As a consequence, we have to employ more sophisticated methods to measure the treatment effect.

3 Empirical Analysis

We analyze the effect of being committed to an emission target under the KP for the major GHG emitters. Out of the top ten GHG emitting countries, accounting for approximately 82% of total baseline emissions of countries with binding emission targets under the KP, we dropped the 3 Eastern European countries Poland, Russia and the Ukraine for two reasons. First, at the time of adoption of the KP in 1997, these countries exhibited emission levels far below their emissions target due to the severe economic downturn during the 1990s which followed the breakdown of the Former Soviet Union (FSU). As these countries were not expected to reach emissions levels at or even above their Kyoto targets in the near future – despite their economic recovery –, they had little economic incentives to reduce emissions. Second, reliable data for these countries is only available since the breakdown of the FSU. The remaining seven countries are Australia, Canada, France, Great Britain, Germany, Italy and Japan which are still responsible for approximately 44% of total baseline GHG emissions of the countries with binding emission targets under the KP.

3.1 Data

The data used in the present paper stems from two different sources. Data on all environmental, economic and structural variables are taken from the World Development Indicators published by the World Bank.[7] Additional information on the KP stems from the United Nations Framework Convention on Climate Change (UNFCCC).[8] Table 1 show the summary statistics for all data used in the empirical analysis.

[6] In March 2001 the USA, despite signing the KP, announced not to ratify. As a consequence, we consider the USA as "non-treated", i.e. a country *without* a binding GHG emission target under the KP. In fact, the USA is the only Annex B country which did not eventually ratify the KP.
[7] Visited online at: http://data.worldbank.org/data-catalog.
[8] Visited online at: http://unfccc.int.

Table 1: Summary statistics

Variable	Mean	Std. Dev.	Min.	Max.	N
Non-Annex B					
MANU	11928621509.443	82705616850.213	773839.759	1614700000000	2622
ALNU	5.16	10.511	0	119.449	2336
EPKW	70140702482.877	357438570691.998	7000000	4147708000000	2336
EPEU	62524.958	200521.584	0	1697347	2336
EUEU	54353.663	229364.539	28	2310961	2336
CO2	85190.464	474493.211	3.664	5793205.36	3863
COIN	2.146	1.257	0.021	13.267	2302
GDPC	6154.154	9120.411	150.807	95434.183	3218
POPT	26660692.466	114490967.061	7519	1296075000	4257
INFL	49.098	560.718	-100	23773.132	2825
Annex B					
TARG	0.965	0.11	0.72	1.27	925
MANU	66139216422.94	151990394256.496	531009733.305	1072629923305.696	485
ALNU	15.685	16.62	0	75.664	820
EPKW	152961097560.976	219231222045.182	358000000	1082152000000	820
EPEU	71621.874	153729.911	26	1280255	820
EUEU	89873.838	130951.932	1497	870002	820
CO2	231551.234	384389.932	1546.208	2548101.457	889
COIN	2.452	0.652	0.648	4.067	809
GDPC	20531.948	9806.405	3429.97	65798.529	820
POPT	23430613.824	33251078.658	25207	148689000	925
INFL	35.979	224.01	-13.845	4734.914	747

Note: TARG: Greenhouse Gas emission target (% of base year); MANU: Manufacturing, value added (constant 2000 US$); ALNU: Alternative and nuclear energy (% of total energy use); EPKW: Electricity production (kWh); EPEU: Energy production (kt of oil equivalent); EUEU: Energy use (kt of oil equivalent); CO2: CO2 emissions (kt); COIN: CO2 intensity (kg per kg of oil equivalent energy use); GDPC: GDP per capita, PPP (constant 2005 international $); POPT: Population, total; INFL: Inflation, consumer prices (annual %).

We face two challenges inherent in the KP and the global scope of the problem. First, the KP allows for flexibility mechanisms such as Emissions Trading (ET), Joint Implementation (JI), and the Clean Development Mechanism (CDM). By trading emission permits (ET) or joint emission reduction projects (JI) treated countries would affect each others' GHG emissions, implying that the stable unit treatment value assumption (SUTVA) would be violated. In addition, treated countries would affect the emissions of countries in the control group via CDM projects. As a result, affected non-treated countries would have to be excluded from the control group. Therefore, flexibility mechanisms may harm the identification of the targeted treatment effect. In order to prevent biased estimates, we limit the analysis to 2004, as from 2005 onward several flexibility mechanisms became important. For instance, the EU emissions trading system (EU-ETS) started in 2005. Moreover, the clean development mechanism (CDM) was virtually non-existent until 2005, after which the number of credited projects skyrocketed.[9] As we consider the adoption of the KP in December 1997 as the treatment event (see Section 2), we

[9] See the UNEP RISO Centre database available online at: http://cdmpipeline.org.

analyze the effect of the targets for the period from 1998 to 2004 using 1980 to 1997 as the pre-intervention period. As an additional robustness check, we also estimated our models with an extended post-intervention period including 2008, although results have to be treated with caution due to the use of flexibility mechanisms (see Section 3.4.2).

Second, as a response to the binding emission targets, treated countries may decrease the domestic production of "dirty goods" and increase their imports from non-treated countries. This response would affect emissions of both treated and non-treated countries and such a bias can neither be quantified nor excluded from the analysis.[10] As this interference would lead to a clear overestimation of the treatment effect,[11] this problem only applies to the UK, the only country for which we find a significant treatment effect.

Obviously, reducing GHG emissions against BAU emissions is not a one shot decision but an ongoing process over time: incentives for reducing GHG emissions have to be incorporated into national legislation and the energy sector has to adjust to these new circumstances (Olmstead and Stavins 2007). Thus, one expects that countries willing to put serious effort into reducing GHG emissions gradually diverge from their BAU emission paths. This view is supported by the KP itself, which explicitly states:

- §3(2): Each Party included in Annex B shall, by 2005, have made demonstrable progress in achieving its commitments under this Protocol.
- §6(1,d): The acquisition of emission reduction units shall be supplemental to domestic actions for the purposes of meeting commitments under Article 3.

Thus, compliance with the KP not only involves noticeable efforts until 2005, but also limits the use of flexible mechanisms to fulfill the emission target under the KP.

Another obstacle to the analysis is that data on the emissions of the six greenhouse gases controlled under the KP is only available for Annex B countries. As a consequence, we use CO_2 emissions as a proxy for GHG emissions in our analysis. This is justified by the fact that CO_2 emissions are by far the most important GHG, as they amount for more than 80% of total GHG emissions worldwide (82.8% in 2007, see UNFCCC). Moreover, the correlation between CO_2 and other GHG emissions for all countries for which we

[10] The carbon content of traded goods is not subject of our analysis, as it is not regulated under the KP. See Aichele and Felbermayr (2011) for further discussion on this topic.

[11] The import of "dirty goods" would reduce domestic GHG emissions for the importing (Annex B) countries while at the same time increase emissions of the exporting (non-Annex B) countries. As a consequence, emissions of non-treated countries would increase due to the KP leading to a higher counterfactual emission path. Thus, the difference between the two (the biased treatment effect) would be larger than the true treatment effect.

have data on the latter is about 0.90. In order to render countries more comparable, we construct what we call *proportional targets*, which is CO_2 emissions in 1990 multiplied by the emission target of the KP in percent.

3.2 Differences-in-Differences, Synthetic Controls and Causal Inference

It is the aim of the present paper to elicit the treatment effect of being committed to a specific emission target under the KP. The classical matching literature calls this the (average) treatment effect on the treated (ATT) (Caliendo and Kopeinig 2008). The main challenge for estimating such an effect is that the researcher is confronted with a missing data problem (Rubin 1976). Obviously, one cannot observe the same country at the same time having both a binding emission target and no emission target. In order to overcome this problem one could compare the average CO_2 emissions of countries with targets to those that have none. However, as we have to deal with observational data, the researcher cannot randomly assign treatment, as it would be necessary for this approach to yield valid results. In our case it is most probably true that countries with (I) and without (N) binding emission targets may differ systematically with respect to their emissions (Y). One important consequence is that the assignment of emission targets cannot be treated as ignorable (Rubin 1976, 1978, 2005). More formally this implies

$$Pr(I|Y(0), Y(1)) \neq Pr(I|Y) \ , \qquad (1)$$

where (0) 1 indicate the outcome in case of (no) treatment (Rubin 1976). Therefore, one cannot simply regress Y on a dummy for I together with some covariates in order to estimate the treatment effect for country i at time t (Abadie et al. 2010), i.e.

$$\alpha_{it} = Y_{it}^{I} - Y_{it}^{N} \ , \qquad (2)$$

as the level of Y may itself influence I.

There are several potential strategies to solve this problem (Imbens and Wooldridge 2009). In cases as ours, where different groups are either exposed or not exposed to some kind of treatment over a certain time period, the most often applied method is the differences-in-differences (DD) estimation (Bertrand et al. 2004). More recently Abadie and Gardeazabal (2003) and Abadie et al. (2010) introduced a synthetic control method that originates from the case study literature. It allows for high levels of flexibility when estimating treatment effects for the above mentioned setup.

In our opinion, the synthetic control approach exhibits two key advantages over the DD estimation which renders it particularly suitable for the present research question. First, the synthetic control method allows to estimate the counterfactual emissions path for every single country and every year following the adoption of the KP. Thus, we do not only get an average effect for all countries under investigation, but we are also able to account for country-specific developments and characteristics. For example, the treatment is very heterogenous as targets range from 79% (Germany) to 108% (Australia) for the countries under investigation. Second, as countries are analyzed separately, different countries may be matched with respect to different characteristics. This is important, as emissions and emission reductions may have different underlying causes.

In what follows, we first apply traditional DD and Panel estimators to quantify the treatment effect for KP emission targets for all countries in our dataset. However, we shall argue that due to several shortcomings of the available data it is not advisable to interpret these results as the real treatment effects. We then apply the synthetic control method and contrast our findings with respect to the DD and Panel estimates.

3.3 Difference-in-Difference and Panel Estimates

The most straightforward approach to analyze a treatment effect if treated and non-treated groups differ and data stretches from some time prior to the treatment (pre-intervention period) to some time past the treatment (post-intervention period) is to apply differences-in-differences (DD) estimation (Ashenfelter 1978, Ashenfelter and Card 1985). In its simplest form with two groups and two periods it can be written as:

$$\pi = (Y_{11} - Y_{10}) - (Y_{01} - Y_{00}) \ , \tag{3}$$

where Y_{10} (Y_{00}) and Y_{11} (Y_{01}) denote the outcome of the treated (non-treated or control) group before and after the treatment. Likewise, the DD approach can be expressed as a regression of the type

$$Y_{it} = \alpha + \gamma D_t + \delta G_i + \pi \, G_i \cdot T_t + \epsilon_{it} \ , \tag{4}$$

where i and t denote unit and time, D is a dummy variable equal to one in the post-treatment period and G is a dummy variable equal to one if a unit is exposed to the treatment. Then, the parameter estimate π of the interaction term is the DD estimate

Table 2: Differences-in-Differences (DD) estimates for the treatment effect

	(1)	(2)	(3)	(4)	(5)	(6)
treatment	-0.302	-0.325	-0.157	-0.00310	-0.00138	-0.0000782
	(0.001)	(0.004)	(0.052)	(0.488)	(0.780)	(0.989)
N	4752	4102	4027	2332	1794	1752
R^2, adjusted	0.212	0.190	0.137	0.996	0.997	0.997

Note: p-values in parentheses. Columns 1–3 present OLS estimates with clustered standard errors using the approach in equation (4). Columns 4–6 display results for equation (5) with robust standard errors including time and year fixed effects and several covariates (GDP per capita, percentage of alternative and nuclear energy consumption, GDP per unit of energy use, CO_2 intensity, total population). Columns 1 and 4 show results for all available observations, columns 2 and 5 for 10 selected Annex B countries (Australia, Canada, France, Germany, Great Britain, Italy, Japan, Poland, Russia and the Ukraine), and columns 3 and 6 for the subset of seven Annex B countries that we analyze in Section 3.4.

of the treatment effect. Table 2 shows DD estimates of the form presented in equation (4) in columns 1–3.

However, this basic DD estimator does neither account for the panel structure of our data nor for any covariates. Controlling for both results in a panel data model of the type

$$Y_{it} = \alpha + \beta X_{it} + F_i + T_t + \pi \, G_i \cdot T_t + \epsilon_{it} \ , \tag{5}$$

which is, in general, estimated via first differences or fixed-effects (within transformation) estimation. In addition to the model of equation (4), this specification includes unit and time fixed-effects F and T, as well as a vector of covariates X. Again, the estimate for π is the treatment effect (Galiani et al. 2005). Results for this specification are shown in columns 4–6 of Table 2.[12]

We find a significant and negative effect of KP targets for our basic DD specification in columns 1–3 independent of the subset of investigated countries. The estimates range from around -.15 to -.3. However, including covariates and accounting for the panel structure, as done in columns 4–6, the effects drop both in economic and statistical significance. In fact, we find no evidence for a significant impact of the KP targets on CO_2 emissions on the basis of the results obtained so far. Moreover, the pattern is similar to Aichele and Felbermayr (2011), as both estimates and significance levels drop

[12] In addition to the presented estimates, we also applied an unconfoundedness-based approach as suggested by Imbens and Wooldridge (2009), a panel approach including AR(1) disturbances (Baltagi and Wu 1999) and difference GMM (Arellano and Bond 1991) accounting for potential persistency of the dependent variable. However, none of these approaches yielded significantly different results and are available from the authors upon request.

markable when Eastern European countries are excluded (see the differences for columns 2 and 3 and columns 5 and 6, respectively).

This model could be further extended to allow for time-varying or group-varying effects, serial correlation, etc.[13] However, we argue that for a cross-country dataset of the present type, where effects are expected to vary drastically across countries and years, and characteristics of countries influencing CO_2 emissions may be heterogenous, traditional regression based approaches may be problematic.

3.4 Synthetic Control Method

We account for the particular characteristics of the present dataset and the research question addressed in this paper by employing the synthetic control approach developed by Abadie and Gardeazabal (2003) and Abadie et al. (2010). In fact, we separately estimate the treatment effect of seven selected Annex B countries for each of which a weighted average of control countries serves as an estimate for the counterfactual outcome without the treatment. We argue that this approach is preferable to more traditional estimation methods because it allows for considerable flexibility and can be tailored for each country under investigation. This is of particular importance in our context, as not only treated and non-treated countries are heterogenous but there are also considerable differences among the treated countries in relevant aspects.

To estimate the counterfactuals for Australia, Canada, France, Great Britain, Germany, Italy and Japan we separate the countries for which sufficient information is available in two distinct sets. The first set – the group of treated countries under investigation – consists of these seven Annex B countries with binding emission targets. The second set – the so called donor pool (Abadie and Gardeazabal 2003, Abadie et al. 2010) – consists of all other countries without having binding targets. These are all non-Annex B countries plus the U.S. which did not ratify the KP. We sequentially draw the seven countries from the treated pool and use a synthetic control approach to create the specific counterfactual country via a convex combination of all countries in the donor pool. We follow Abadie and Gardeazabal (2003) and Abadie et al. (2010) in keeping the restriction of no extrapolation. To increase the comparability of countries we transform all data to an index with 1990 as the base year (Cavallo et al. 2010).

[13] See, for example, Bertrand et al. (2004) and Hansen (2007a,b). For an overview of recent developments, see Imbens and Wooldridge (2009).

For the general case in which Y_{it}^N denote the emissions of country i at time t without treatment (N), and accordingly, Y_{it}^I with treatment (I), the treatment effect would be described by equation (2). Now suppose that there are $J+1$ countries where $J=1$ denotes the treated country – which, in our case, corresponds to a binding emission target under the KP – and $j=2,\ldots,J+1$ are all untreated countries in the donor pool. For the treated country we have data about the actual emission path (Y_{1t}^I), but we are ignorant about the counterfactual emissions which would have occurred if this country would not have been subject to the treatment (Y_{1t}^N for $t>1997$). Thus, we have to find an estimate for Y_{1t}^N in order to obtain an estimate for the treatment effect α_{1t}:

$$\alpha_{1t} = Y_{1t} - Y_{1t}^N \ . \tag{6}$$

Abadie and Gardeazabal (2003) and Abadie et al. (2010) propose to make use of the observed characteristics of the countries in the donor pool. The underlying idea is to find weights $W=(\omega_2,...,\omega_{J+1})'$, with $\omega_j \geq 0$ for $j=1,\ldots,J+1$ and $\sum_{j=2}^{J+1}\omega_j=1$, such that the weighted average of all countries in the donor pool resembles the treated country with respect to GHG emissions in the pre-intervention period and all other relevant aspects (Z). Formally, we seek W such that:[14]

$$\sum_{j=2}^{J+1} \omega_j^\star Y_{jt} = Y_{1t} \quad \text{for all } t < T_0 \qquad \text{and} \qquad \sum_{j=2}^{J+1} \omega_j^\star Z_j = Z_1 \ . \tag{7}$$

Then $\sum_{j=2}^{J+1}\omega_j^\star Y_{jt}$ for $t \geq T_0$ is an estimate for the unobserved counterfactual emissions path Y_{1t}^N, and we obtain the following estimate for the treatment effect:

$$\widehat{\alpha}_{1t} = Y_{1t} - \sum_{j=2}^{J+1} \omega_j^\star Y_{jt} \ , \quad t \geq T_0 \ . \tag{8}$$

In general, a vector W such that equations (7) hold may not exist (in particular, if the weights $w_j \geq 0$ and, thus, extrapolation is prohibited). However, one can choose the weights such as to

$$\min_W (X_1 - X_0 W)' V (X_1 - X_0 W) \ , \tag{9}$$

where X_1 denotes a $(k \times 1)$ vector of pre-intervention characteristics of the treated country, which may include the pre-intervention emission path, and X_0 denotes a $(k \times J)$ matrix of the same variables for the J countries in the donor pool. The symmetric and

[14] In our case $1980 \leq t \leq 2004$ and the pre-intervention period T_0 is $1980 \leq T_0 \leq 1997$.

positive definite matrix V weights the relative importance of the various characteristics included in X. Obviously, the optimal weights W depend on the weighting matrix V. We follow Abadie and Gardeazabal (2003) in choosing V such that the difference of the pre-intervention emission path of the treated country and its synthetic counterpart is minimized. For further discussion on the synthetic control method including several extensions, see Abadie et al. (2010).

As the synthetic control method itself does not provide standard errors to infer statistical significance, Abadie and Gardeazabal (2003) and Abadie et al. (2010) suggest to run placebo or permutation tests. The underlying idea is to predict counterfactual emission paths for countries in the donor pool, i.e., for countries without any treatment.[15] If and only if the gap between the actual emission path and the predicted one is the largest for the country where the treatment really occurred, then one can say that its development is "significantly" different from the business-as-usual scenario (Abadie and Gardeazabal 2003, Abadie et al. 2010).[16] In addition, in Figures 7–9 in the appendix we report results on the root mean squared prediction error (RMSPE) ratio as in Abadie et al. (2010), and "p-values", as suggested by Cavallo et al. (2010).

3.4.1 Results

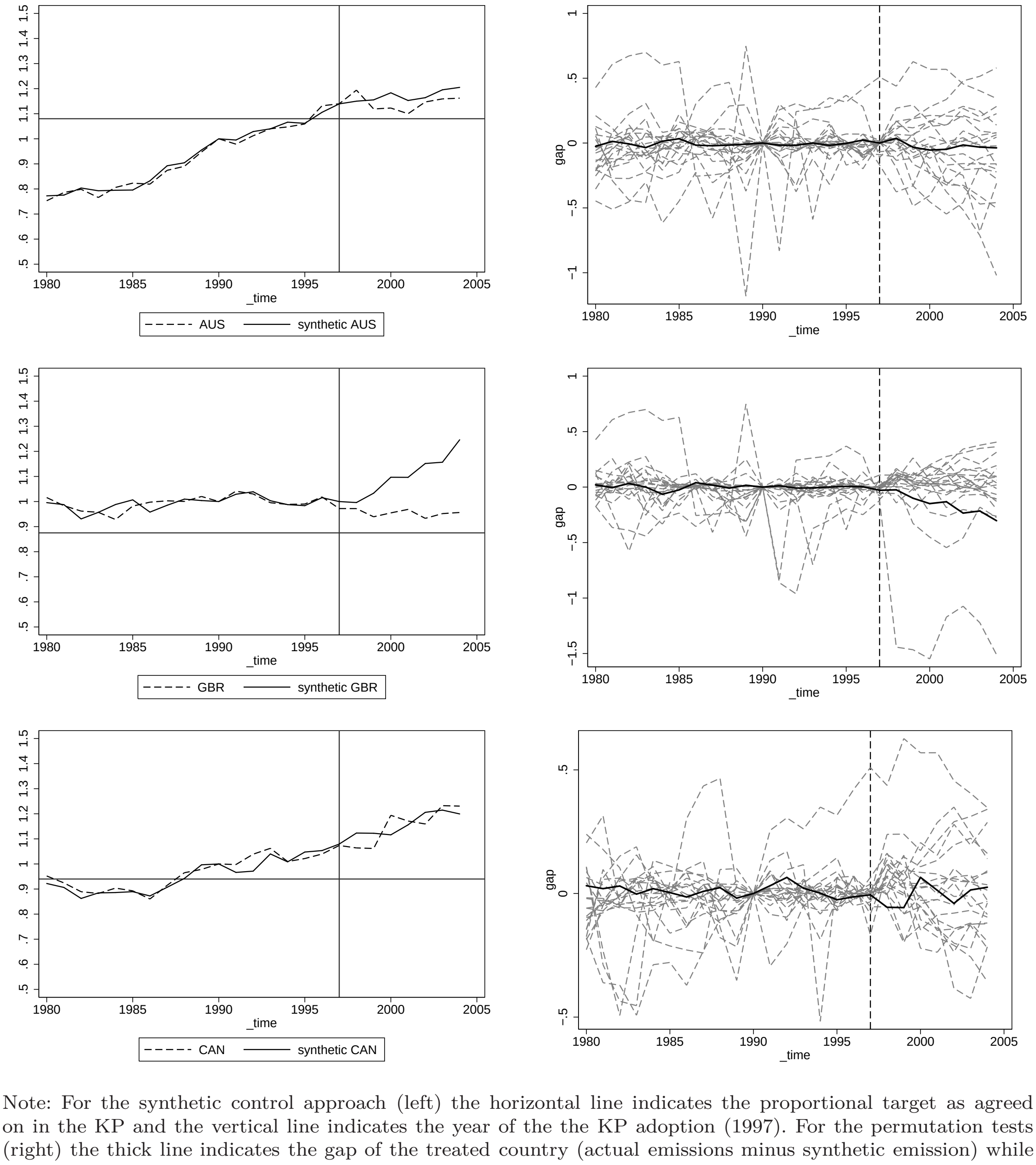
In Figures 2–4 we show the results for the seven countries under investigation. For each country we plot the predicted counterfactual and the actual emission paths for $1980 \leq t \leq 2004$. In addition, the graphs show results for the placebo tests, as mentioned above. Additional information on the chosen characteristics X_0 and X_1, weights W, the predictor balance and the root mean squared prediction error (RMSPE) are given in the appendix.

The results are unambiguous for Australia, Canada and Italy. Neither do the predicted emission paths deviate from the actual ones in any considerable amount nor does the inference analysis show any kind of higher gap between actual and predicted paths of these countries relative to donor countries. Thus, the findings do not support the hypothesis that the Kyoto agreement did change emissions of Australia, Canada and Italy until 2004. For Japan predicted CO_2 emissions are even below actual emissions,

[15] For the inference analysis we draw a random sample of 20 countries from the donor pool, while keeping the same elements for X.

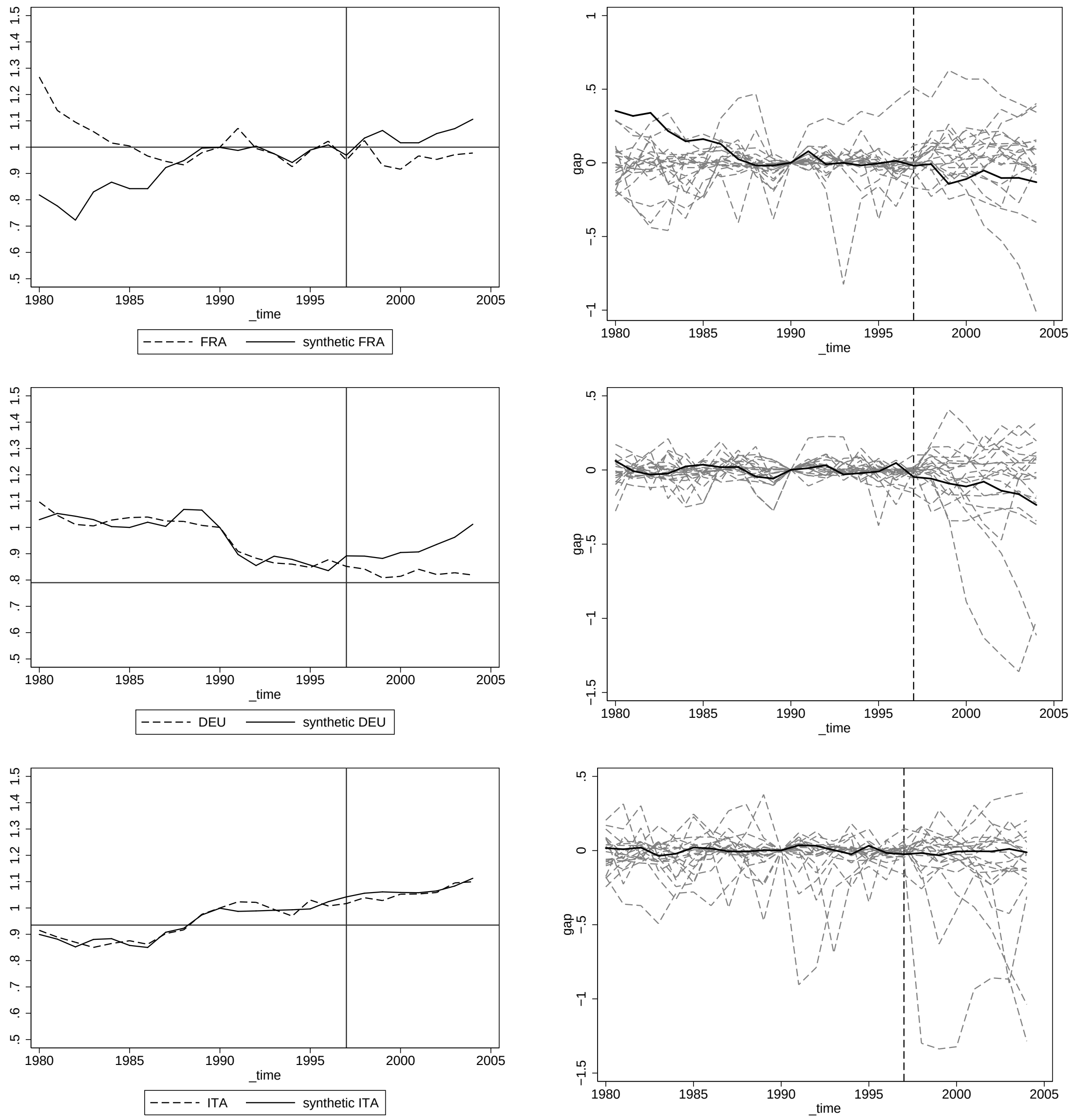
[16] Alternatively, one could employ a time series approach based on the actual and predicted outcome, as proposed by Hsiao et al. (forthcoming).

Figure 2: Synthetic matching and permutation tests for Australia, Great Britain and Canada



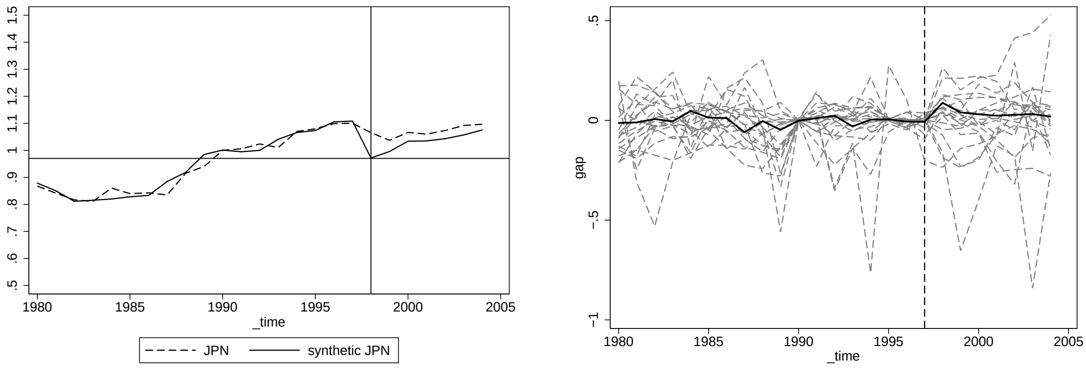
Note: For the synthetic control approach (left) the horizontal line indicates the proportional target as agreed on in the KP and the vertical line indicates the year of the the KP adoption (1997). For the permutation tests (right) the thick line indicates the gap of the treated country (actual emissions minus synthetic emission) while the dashed lines indicate the corresponding gaps for the random sample of donor countries.

Figure 3: Synthetic matching and permutation tests for France, Germany and Italy



Note: For the synthetic control approach (left) the horizontal line indicates the proportional target as agreed on in the KP and the vertical line indicates the year of the KP adoption (1997). For the permutation tests (right) the thick line indicates the gap of the treated country (actual emissions minus synthetic emission) while the dashed lines indicate the corresponding gaps for the random sample of donor countries.

Figure 4: Synthetic matching and permutation tests for Japan



Note: For the synthetic control approach (left) the horizontal line indicates the proportional target as agreed on in the KP and the vertical line indicates the year of the the KP adoption (1997). For the permutation tests (right) the thick line indicates the gap of the treated country (actual emissions minus synthetic emission) while the dashed lines indicate the corresponding gaps for the random sample of donor countries.

indicating a negative treatment effect (see left of Figure 4). However, this effect is not significant according to the inference analysis shown in Figure 4 (right).

France shows a very specific development of CO_2 emissions (Figure 3, top left). We observe a considerable decrease during the 1980s and a fluctuating development thereafter. In fact, it turned out to be challenging to match the CO_2 emissions of France with those of other countries. In order to keep the RMSPE in a considerable range, we restricted the period over which the RMSPE is minimized to 1988–1997. In doing so, we find a sizeable difference between actual and synthetic emissions (see top left of Figure 3). However, also being at the outskirts of the cloud generated by the placebo study, Figure 3 (top right) does not show a significantly different gap for France relative to its donor countries.

Also Germany shows a specific development of CO_2 emissions as a result of the reunification in 1990 and the accompanied collapse of (dirty) industries in the eastern part. Germany shows an emission path similar to France. There is considerable deviation of the counterfactual predicted path from the observed path in Figure 3 (middle left), but the placebo study in Figure 3 (middle right) renders this result insignificant.

We also find a different development for the synthetic Great Britain and the actual Great Britain (see middle left of Figure 2). In 2004 Great Britain's CO_2 emissions would have been approximately 30 percent higher in the absence of the KP emissions target. Looking at the corresponding inference analysis in Figure 2 (middle right) there is some evidence that the gap between the actual and synthetic Great Britain is exceptional relative to the placebo study (except for one obvious outlier). Thus, we cannot reject the hypothesis that the Kyoto Protocol target did reduce Great Britain's GHG emissions. This result is also supported by the RMSPE ratios and the "p-values" (see Figure 8 in the appendix).

3.4.2 Robustness Checks

In the following, we show that our results are robust to a variety of setup-alterations.

Significant treatment effect for the UK

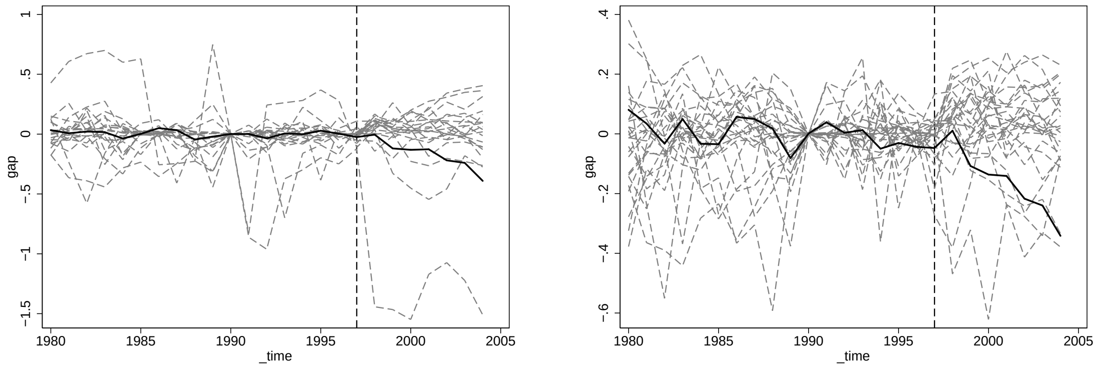
As the UK is the only country for which there is a significant treatment effect we employed several alternative specifications. First, we re-estimated the counterfactual emission path for the UK excluding the USA from the donor pool. One might argue that the synthetic UK is driven by a very specific emission path of the USA (weight: .449). However, results remain robust and can be found in Figure 5 (left).

By design, the KP exhibits a clear selection bias between treated (roughly the developed world) and non-treated countries (rest of the world). One might question whether developing countries are useful in constructing synthetic counterfactuals for developed countries. In fact, out of the 20 countries chosen from the donor pool to match the seven countries under consideration, only six countries are considered as lower and lower middle income countries according to the World Bank classification. As another robustness check, however, we re-ran the analysis for the UK restricting the donor pool to countries classified as high and upper middle income countries. The treatment effect remained robust – although it is less significant – and is displayed in Figure 5 (right).

Extended treatment period

As discussed in Section 3.1, the use of flexibility mechanisms such as emissions trading, joint implementation and clean development mechanism blurs the distinction among the different treated countries and also the distinction between treated and non-treated countries. In consequence, we restricted the treatment period from 1998 to 2004. However, the first commitment period under the KP ranges from 2008 to 2012. Thus, it is certainly of interest to have some information on the treatment effect after 2005. As a consequence, we ran the synthetic control method for an extended treatment period

Figure 5: Robustness Checks for the UK: Excluding the USA (left) and the USA and developing countries (right) from the donor pool.



Note: The horizontal axis displays the gap between the synthetic and actual emission path for the UK (i.e., the treatment effect for the post-intervention period) and the vertical line indicates the year of the KP adoption (1997).

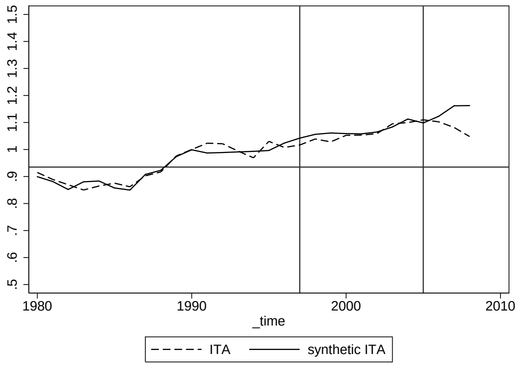
ranging from 1998 to (and including) 2008. However, one should keep in mind that result may be biased between 2005–2008.

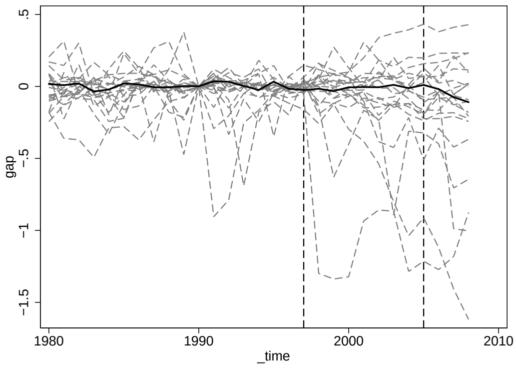
Results for the extended treatment period show the same pattern as the benchmark results for Australia, Great Britain, Canada, France, Germany and Japan. Qualitatively, the results are the same as for the original post-intervention period (results available on request). For Italy (Figure 6), however, results change for the period 2005–2008 as we do find a treatment effect in the years 2007 and 2008. However, the inference analysis renders this treatment effect insignificant.

4 Discussion

The DD estimates show significant treatment effects for all investigated sample sizes if we do not control for any covariates and the panel structure in our data. Accounting for GDP per capita, percentage of alternative and nuclear energy consumption, GDP per unit of energy use, CO_2 intensity, total population, and including country and year fixed-effects the treatment effect remains negative but becomes insignificant. This result is supported by our synthetic control analysis. In summary, we can rule out significant treatment effects for the six countries Australia, Canada, France, Germany, Italy and Japan, and we find a clear treatment effect for Great Britain.

Figure 6: Synthetic matching and permutation tests for Italy for an extended treatment period 1998 to 2008





Note: For the synthetic control approach (left) the horizontal line indicates the proportional target as agreed on in the KP and the vertical line indicates the year of the the KP adoption (1997). For the permutation tests (right) the thick line indicates the gap of the treated country (actual emissions minus synthetic emission) while the dashed lines indicate the corresponding gaps for the random sample of donor countries.

Our results clearly show the advantage of the synthetic control method over the traditional differences-in-differences (DD) approach in eliciting the causal effect of binding emissions targets under the Kyoto Protocol (KP). Despite the clear selection bias in the treated and non-treated group, we are able to construct counterfactual emissions paths for all seven countries under investigation, which reasonably match the observed emissions in the pre-treatment period. This is not only evident from the graphs in Figures 2, 3 and 4 but also from the small root mean square prediction errors (RMSPE) shown in the appendix.

Another advantage over the traditional DD approach is that treatment effects can be estimated for each country individually. This allows to individually tailor the counterfactual synthetic country to the idiosyncracies of each treated country (i.e., the individual emission target). In fact, the table in the appendix shows that we not only used different variables to be matched for the seven countries but also that the countries chosen from the donor pool to construct the counterfactual country differ considerably among the seven countries. In total 20 countries were chosen from the donor pool to match all seven treated countries.

Our results also fit well with the assessment of the "demonstrable progress reports" all Annex B countries with binding emissions targets under the KP had to compose in order to report about their emissions reductions progress until 2005 and the planned measures to achieve compliance with the KP targets over the commitment period from

2008–2012.[17] Australia did not submit such a progress report, as it only ratified the KP in 2007. In addition, the former Australian government strictly opposed ratification of the KP as it feared economic consequences from emissions reductions. In fact, Australia experienced the fifth highest greenhouse gas emissions per capita in 2005 according to the World Resources Institute. Therefore, it is not surprising that up to 2004 Australia's CO_2 emissions followed a business-as-usual path. In its progress report Canada admitted its weak progress towards complying with the KP target, despite substantial (and costly) policy measures and strong support from the general public. Canada claims its national peculiarities of high population growth, strong economic growth and very drastic growth in the natural resource sector are at least partly to blame. As a result, on December 12th 2011 Peter Kent, the environment minister, announced that Canada will contract out of the protocol. Also Japan and Italy admit that their progress with respect to emission restrictions is unsatisfactory. Although they promised to comply with the KP, they plan to achieve this rather by means of the flexible mechanisms under the KP and less due to own emission reductions. France reported to be close to its KP target. France claims that this success is due to its climate action plan, in which the government and the private sector agreed on even more ambitious abatement targets. Germany reported to be on the right track (17.4% reduction of GHG emissions in 2004 compared to 1990). Apart from the re-unification and the associated collapse of the "dirty" industry in former Eastern Germany, Germany profitted from an aggressive promotion of renewable energies the total output of which triplicated from 1990 to 2004. Also Great Britain stated its full support of the KP and reported a drop of 14.6% of GHG emissions compared to base year levels.[18] In fact, Great Britain exhibits demanding complementary climate change policies. It has adopted a domestic goal to reduce 20% of CO_2 emissions by 2010 against 1990, and a long-term goal of a 60% reduction until 2050.

5 Conclusion

The Kyoto Protocol (KP) has been widely criticized by the public press and the scientific community alike. In particular, issues concerning equity, efficiency and cost-effectiveness have been raised. In this paper, we asked in how far the KP lived up to its primary goal, the reduction of domestic GHG emissions in the industrialized world. To answer this question, we analyzed the development of CO_2 emissions for seven major GHG emitters with binding emission targets under the KP with a synthetic control approach. With

[17] Available online at: http://unfccc.int
[18] However, these 14.6% included accountable emission changes due to changes in land use.

the exception of Great Britain, we find little evidence for a significant treatment effect, i.e., countries with binding emissions targets did not emit less CO_2 over the period from 1998–2004 than they would have if they would not have been subject to emission targets under the KP.

In light of these findings and the additional concerns raised by other authors, we doubt that a continuation of the KP in its present form – even if extended to include countries in transition – is advisable. As a consequence, we see the focus on domestic actions rather as a dead end than a last resort for future climate policy. Instead we follow Prins and Rayner (2007) and Olmstead and Stavins (2007) in their advice to completely rethink the necessities of an international environmental agreement and to implement an according architecture. Of course, as the last climate negotiations proved markedly, this is easier to be said than done.

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Appendix

The following tables give additional information on the chosen weights W, the predictor balance, and the root mean squared prediction error (RMSPE) for the synthetic controls of the seven countries under investigation.

Australia				
RMSPE	0.0157732			
Elements of X	Treated	Synthetic	Country Codes	Weights
CO2 ind(1993)	1.0400455	1.0398973	CYP	.042
CO2 ind(1995)	1.0592113	1.0616889	GAB	.01
CO2 ind(1997)	1.1396776	1.1392478	JAM	.034
GDPC ind	.95673891	.96864245	MEX	.314
COIN ind	.97256694	.97287455	TUR	.207
POPT ind	.9745784	.97723708	USA	.296
INFL ind	.81604636	1.2218789	ZWE	.097
POPT ind(1998(1)2004)	1.1374694	1.174411		
INFL ind(1998(1)2004)	.37898272	1.300556		

Great Britain				
RMSPE	0.0223088			
Elements of X	Treated	Synthetic	Country Codes	Weights
CO2 ind(1985)	.98182636	1.0067237	JAM	.048
CO2 ind(1986)	.99747264	.95787756	NGA	.078
CO2 ind(1991)	1.0413698	1.0290785	TTO	.189
CO2 ind(1996)	1.0183473	1.0154383	USA	.449
CO2 ind(1997)	.97193569	.99989701	ZAR	.236
EPKW ind	.96853412	.95257611		
EUEU ind	.9966448	.95896528		
GDPC ind	.94068872	.99119126		
COIN ind	.99882423	1.0539675		
POPT ind	.99770882	.98490668		

Canada				
RMSPE	0.0238689			
Elements of X	Treated	Synthetic	Country Codes	Weights
CO2 ind(1993)	1.0623691	1.0400123	COL	.055
CO2 ind(1996)	1.0395643	1.0534184	ECU	.05
CO2 ind(1997)	1.0736697	1.0794488	GAB	.035
ALNU ind	1.0127441	.97235728	JAM	.147
EPKW ind	1.0061366	.97733622	NGA	.026
EPEU ind(1980(1)1989)	.84987291	.81756977	USA	.381
EPEU ind(1990(1)1997)	1.1776673	1.0920899	VEN	.216
EUEU ind	.99413004	.9836014	ZAR	.09
GDPC ind	.95733257	.98738612		
COIN ind	.97520806	.98097175		
POPT ind	.9800609	.97999068		
POPT ind(1998(1)2004)	1.1187162	1.2026673		

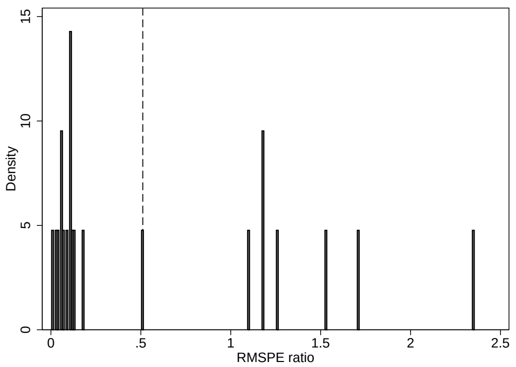
France				
RMSPE	0.0292088			
Elements of X	Treated	Synthetic	Country Codes	Weights
CO2 ind(1988(1)1992)	.99571389	.98722841	DZA	.257
CO2 ind(1993)	.97513235	.97499269	ECU	.068
CO2 ind(1997)	.95102745	.96936102	JAM	.093
ALNU ind(1991(1)1995)	1.088621	1.089297	MEX	.158
EPKW ind(1985(1)1997)	1.0413793	1.039848	SDN	.04
EPEU ind(1990(1)1997)	1.1060159	1.0667473	ZAR	.253
EUEU ind(1991(1)1997)	1.0610689	1.0816054	ZWE	.13
GDPC ind(1988(1)1992)	.98991762	.98892533		
GDPC ind(1993(1)1997)	1.0335018	.89109397		
COIN ind(1990(1)1997)	.94128588	.92026878		
POPT ind	.98987935	.96578784		
POPT ind(2000(1)2004)	1.0517759	1.2725568		
INFL ind(2000)	.50277597	2.2533562		

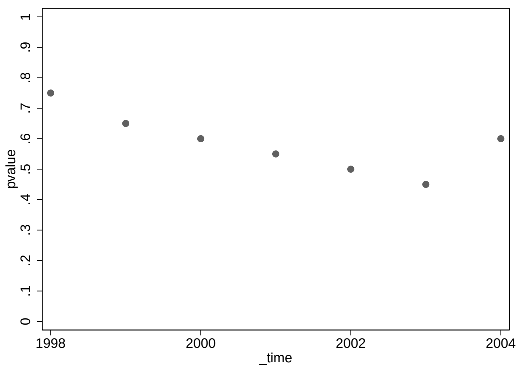
Germany				
RMSPE	0.0331868			
Elements of X	Treated	Synthetic	Country Codes	Weights
CO2 ind(1986)	1.0394883	1.0197482	ALB	.212
CO2 ind(1991(1)1995)	.87298849	.87563997	USA	.535
CO2 ind(1996)	.87724149	.83560834	ZMB	.252
CO2 ind(1997)	.85190731	.89189575		
GDPC ind	.95186213	.97540854		
EUEU ind(1980(1)1985)	.98298825	.93133672		
EUEU ind(1992(1)1996)	.96303115	.94764451		
EUEU ind(1997)	.9828915	.97712421		
COIN ind(1980(1)1985)	1.0596507	1.1143252		
COIN ind(1992(1)1996)	.89872442	.87191304		
COIN ind(1997)	.86440253	.85399082		
POPT ind	.99983214	.97052172		
POPT ind(1998(1)2004)	1.0363492	1.1498978		
AGVA ind(2000)	1.1350716	1.3083242		
INFL ind(2000)	.85360497	.83313191		

Italy				
RMSPE	0.020173			
Elements of X	Treated	Synthetic	Country Codes	Weights
CO2 ind(1993)	.99436677	.99110729	DZA	.059
CO2 ind(1996)	1.0077037	1.0237655	JAM	.085
CO2 ind(1997)	1.0166065	1.042118	MEX	.276
ALNU ind	1.2725586	1.0271518	USA	.419
EPKW ind	.9662771	.95543326	ZAR	.158
EPEU ind(1980(1)1989)	.90813811	.88838576	ZWE	.002
EPEU ind(1990(1)1997)	1.1187532	1.0342123		
EUEU ind	.96096949	.96101172		
GDPC ind	.94072787	.97508264		
COIN ind	.9835916	.98390632		
POPT ind	.99934022	.98071053		
POPT ind(1998(1)2004)	1.0092339	1.1972574		

Japan				
RMSPE	0.0213998			
Elements of X	Treated	Synthetic	Country Codes	Weights
CO2 ind(1995)	1.0796613	1.0734271	ALB	.024
CO2 ind(1996)	1.0990455	1.1056268	CUB	.114
CO2 ind(1997)	1.1003619	1.1082995	JAM	.149
ALNU ind	.98048224	1.010609	PRK	.16
EPKW ind	.92501628	.96125783	THA	.041
EUEU ind	.93768214	.93935736	USA	.513
COIN ind	1.0105633	1.0173347		
POPT ind	.98967067	.98717783		
POPT ind(1998(1)2004)	1.029192	1.1177278		

Figure 7: RMSPE ratios and p-values for Japan





Note: The left graph displays the histogram of the RMSPE ratio for 21 countries (treated plus placebo). The dashed line indicates the RMPSE ratio for the treated country under investigation (Japan). The RMPSE ratio is computed by dividing the RMSPE after the treatment by the RMSPE prior to the treatment for each country (Abadie et al. 2010). If and only if the treated country stands out in terms of the size of the ratio (dashed line at the right end of the graph) one can interpret this as evidence for a "significant" treatment effect. For the right graph we follow the approach proposed by Cavallo et al. (2010) and calculate "p-values" for the significance of the treatment effect for each post-intervention year. The exact formula is given by:

$$p\text{-}value_l = \frac{\sum_{j=2}^{J+1} I(\widehat{\alpha}_{1,l}^{PL(j)} > \widehat{\alpha}_{1,l})}{J} \quad (10)$$

and $\widehat{\alpha}_{1,l}^{PL(j)}$ being the estimated effect of placebo (PL) country j at time l after the treatment. Similarly, $\widehat{\alpha}_{1,l}$ is the estimated treatment effect of country 1 at time l.

Figure 8: RMSPE ratios and p-values for Australia, Great Britain and Canada

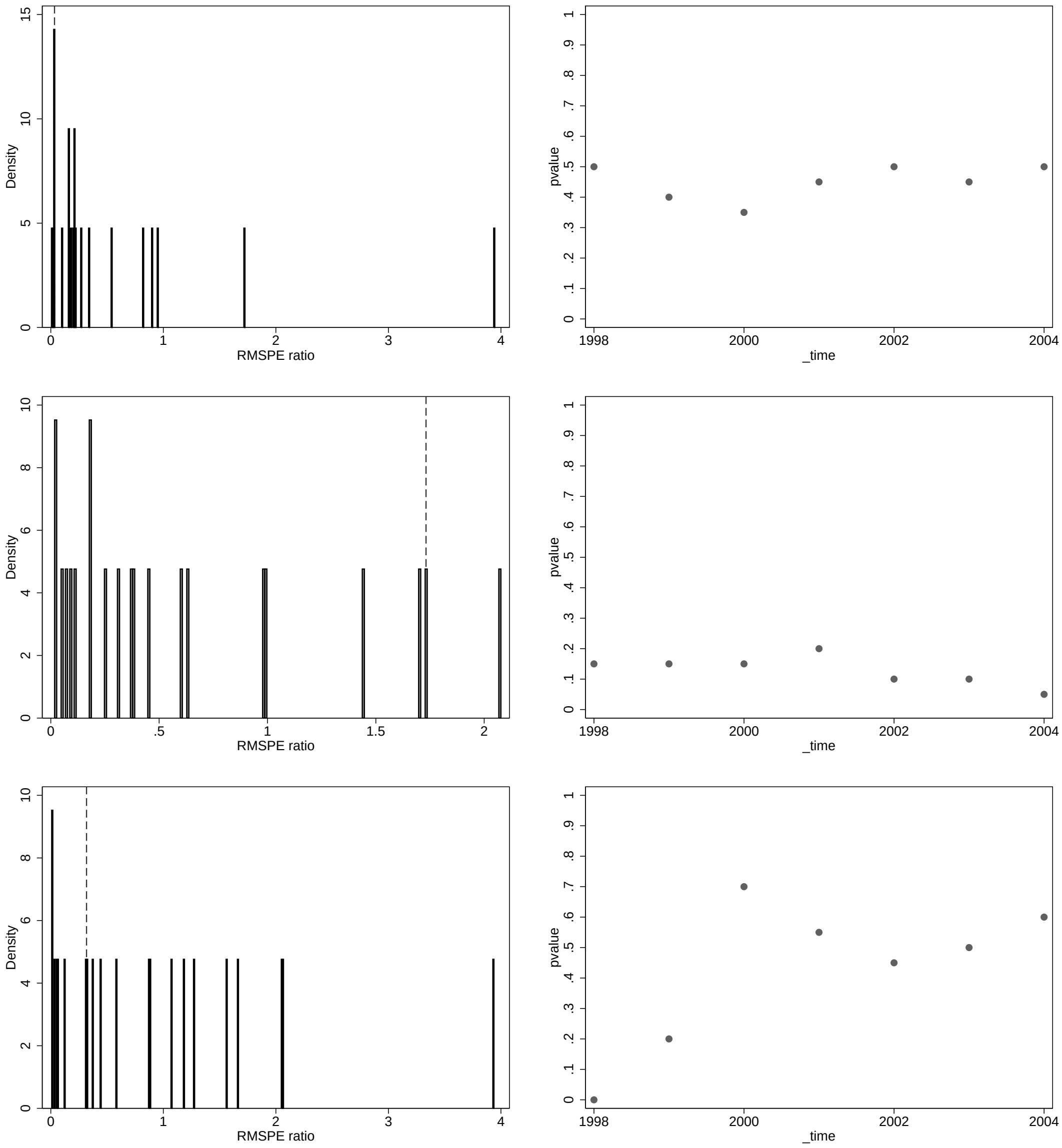


Figure 9: RMSPE ratios and p-values for France, Germany and Italy