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International Environmental Agreement and Trade in Environmental Goods: The Case of Kyoto Protocol

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Abstract

The Kyoto Protocol has received much criticism for its effectiveness as well as the spillover effect (i.e. carbon leakage and competitiveness loss). This paper provides the first evidence for the effect of the Kyoto Protocol on the bilateral trade in environmental goods, which can mitigate and prevent environmental damage. Using the generalized synthetic control method, I construct the counterfactual of trading pairs with Kyoto commitment and show that the export of environmental goods by Kyoto countries increases by 29–30% after the protocol enters into force. The paper further examines the top exporters (Germany and Japan) individually and also reports positive effects. Technology transfer induced by project-based mechanisms under the Kyoto Protocol, in particular Clean Development Mechanism, is found to be the potential driving force.

Keywords Environmental goods · Generalized synthetic control · Gravity model · International environmental agreement · Kyoto Protocol

JEL Classification F14 · Q56

1 Introduction

The Kyoto Protocol (KP) was adopted in 1997 in the hope of mitigating the issue of climate change and global warming. Despite being an ambitious international treaty aiming to reduce greenhouse gas (GHG) emissions to a safe level, it has received a high level of criticism regarding its design and skepticism regarding its effectiveness. For example,

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Copeland and Taylor (2005) suggest that re-examination of the KP is needed because trade theory was neglected in the design. In addition, Zhang and Wang (2011) find that the Clean Development Mechanism, which allows industrialized countries with KP commitments to reach their targets by using carbon offsets from developing countries, does not lead to a decrease in sulfur dioxide emissions. In contrast, several empirical studies show that the protocol has been successful in reducing carbon emissions in legally bound countries (Aichele and Felbermayr 2013a; Grunewald and Martinez-Zarzoso 2016; Maamoun 2019). However, some researches indicate that the decrease in GHG emissions is not necessarily a success, given evidence of carbon leakage (via trade of high carbon content goods) (Aichele and Felbermayr 2012, 2015). Further, Aichele and Felbermayr (2013b) demonstrate that the Kyoto commitments lead to a comparative disadvantage in manufacturing sectors, especially pollution-intensive ones. As a result, the overall picture of the influence of the KP remains unclear.

This paper investigates the effect of Kyoto commitments on trade in environmental goods (EGs). EGs are defined as products that can "measure, prevent, limit, minimize or correct environmental damage to water, air and soil, as well as problems related to waste noise and eco-systems" (OECD 1999). In short, EGs are regarded as products with environmentally beneficial characteristics. EGs are categorized into three groups: pollution management, cleaner technology and resource management. Products in the pollution management concentrate on cleaning the pollution, and are further divided into sub-categories based on the pollution target (e.g. air, waste, noise).[1] The remaining two groups, however, include products that reduce or prevent emissions and use resources more efficiently, for example solar panel.

Studies about the trade flow of environmentally friendly products is relatively scant in the literature. Although previous studies examine these products, they mainly focus on one aspect of EGs (e.g. energy, solar, and wind technology) and do not find causal evidence for the effect of the KP (Costantini and Crespi 2008; Miyamoto and Takeuchi 2018). In contrast to previous work, this paper studies the industry of EGs, yet restricts the examination to products relevant to the purpose of dealing with GHG emissions: air pollution control, environmental monitoring, cleaner technology, and renewable energy subgroups.[2] The statistics of trade of these products (displayed in Fig. 1) suggest that this market has experienced fast-paced growth, especially after 2000. The world trade of these products increased significantly in the early 2000s, which coincided with the ratification period of the KP. A closer examination of Fig. 2 shows that, during the ratification period from 2001 to 2004, the export growth of Kyoto countries outperformed that of non-Kyoto countries, while this trend was the reverse previously. From 2008, the export growth of the two groups performed fairly similarly. Therefore, this suggests that KP ratification plays a role in the export of EGs.[3]

In this study, I follow Aichele and Felbermayr (2013b) and choose the unit of analysis as an exporter–importer pair. Using the bilateral trade of EGs, I apply the generalized

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[1] The specific sub-categories in the pollution management group are (1) air pollution control, (2) wastewater management, (3) solid waste management, (4) remediation and cleanup, (5) noise and vibration abatement, and (6) environmental monitoring, analysis and assessment.

[2] Air pollution control and environmental monitoring belong to the pollution management group, while renewable energy is in the resource management group. Together, they comprised approximately 25% of EG trade value in 2011. Details of the six-digit HS product code in the analysis can be found in Table A2 of Sugathan (2013).

[3] From now on, EGs are used to imply only products in the analysis, unless otherwise indicated.

synthetic control method (GSCM) of Xu (2017) to evaluate the causal effect of the KP on the bilateral export of EGs. In particular, I construct the counterfactual of trading pairs with Kyoto commitments and estimate the average treatment effect on the treated (ATT) on exports. My findings indicate that the protocol commitment leads to an average 29 to 30% increase in the exports of committed countries. The results are robust and consistent in a number of robustness checks. The paper further examines the top two exporters (Germany and Japan) individually and also reports positive effects of the KP on exports of these countries.

This paper contributes to the literature in two important ways. First, it is the first study to provide evidence for the EG trade effect of the KP. Export performance in EGs has been shown to improve after the ratification of the KP. This result aligns with the finding in Costantini and Crespi (2008) although it only suggests the correlation. Second, the paper applies the newly developed methodology, the GSCM, in the gravity model context to estimate the treatment effect on trade. The well-known approach to investigating the trade effect in the international trade literature is to use either the gravity model with fixed-effects or matching difference-in-difference (DID) (as in Aichele and Felbermayr (2013b)). Compared with the DID and synthetic control approach, the GSCM has two major advantages. First, based on the concept of the original synthetic control method (Abadie et al. 2010, 2015), the GSCM also constructs the counterfactual of the treated countries from the untreated ones, so that the treated and synthetic countries have similar outcomes in the pre-treatment periods. In this way, the synthetic control approach can overcome the difficulty of ensuring the validity of the "parallel assumption." Second, the GSCM integrates the synthetic control method and the interactive fixed-effect model by Bai (2009) to synthesize the counterfactual of the treated trading pairs. This allows the method to analyze multiple treated units simultaneously, instead of a one-by-one unit analysis, and provides classical standard errors for statistically significant inference.[4]

My results have important policy implications. Since its first adoption, the KP has been a controversial topic. My results indicate that the KP could have a pro-green trade effect by improving the export performance of the committed countries in terms of EG production. Therefore, alongside findings on the effectiveness of the KP (Grunewald and Martinez-Zarzoso 2016; Maamoun 2019), my findings have implications regarding considering the participation of more countries in the KP, such as China and India, as well as potentially stronger commitments. Further, these findings offer hope to the future of international cooperation regarding environmental issues, such as the 2015 Paris Agreement.

The rest of this paper is presented as follows. Section 2 provides background information on the KP, industry of EG and a brief review of the relevant literature. Section 3 presents the framework and methodology, followed by the data description in Sect. 4. Section 5 discusses the results and robustness checks, while Sect. 6 concludes this paper.

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[4] The synthetic method relies on placebo tests to gauge the uncertainty of the estimated treatment effect. A detailed comparison of the two approaches can be found in Sect. 3.
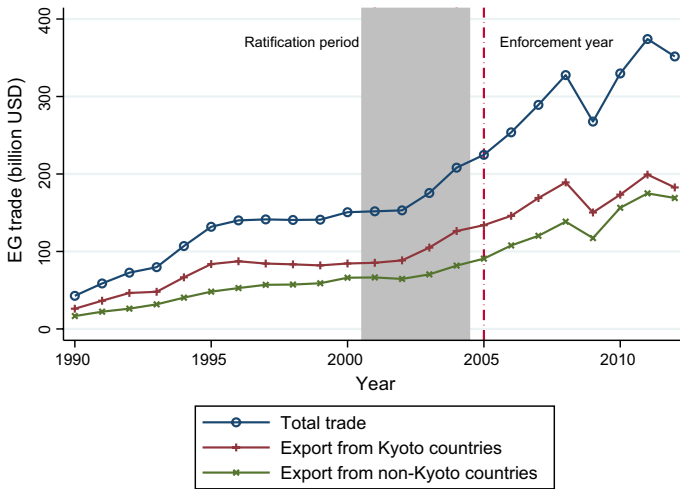
Fig. 1 World trade of EGs during 1990–2012
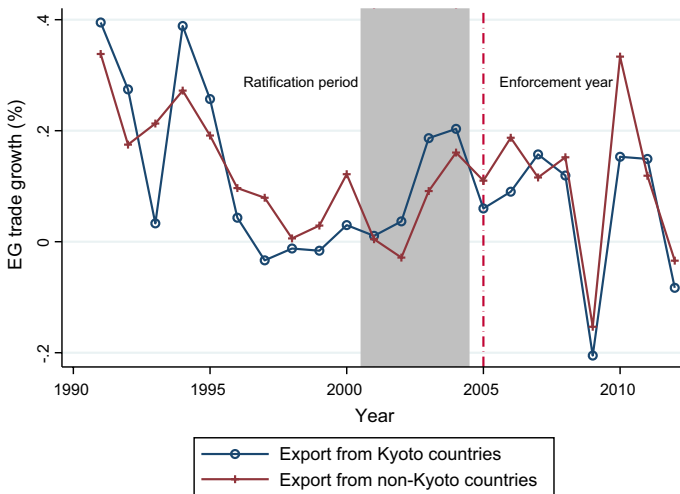
Fig. 2 EG export growth of Kyoto and non-Kyoto countries during 1991–2012

2 Background

2.1 The Kyoto Protocol

The KP was adopted in 1997 as a commitment to reduce GHG emissions and an attempt to slow global warming and fight climate change. With the ratification of Russia and Canada in 2004, the KP entered into force in 2005. Although there are currently 192 parties to the protocol, only a group of countries listed in Annex B of the protocol are committed

to legally binding targets.[5] According to Article 3, these countries agreed to reduce their GHG emissions to at least 5% below their 1990 levels in the first commitment period (2008 to 2012).[6][7] On December 21, 2012, the Doha Amendment to the KP was adopted. The amendment requires acceptance from at least 144 parties (excluding the European Union) for entry into force, yet this threshold was not achieved until October 2020.[8] This results in ambiguity of the validity of the KP beyond 2012, as well as the Doha Amendment.

In addition to domestic emission reductions as a mean of meeting carbon emission targets, the KP introduced three flexible market-based mechanisms: Clean Development Mechanism (CDM), Joint Implementation (JI), and Emissions Trading (ET). In terms of ET, countries can trade initial amount of permitted emissions. Regarding the other two mechanisms, they involve investment in emission reduction projects in host countries. In return, committed countries will earn emission reduction units, which can be counted towards meeting their Kyoto targets. The difference between JI and CDM is host country. In particular, under JI scheme, host country is another Annex B country while CDM focuses on non-Annex B countries, especially developing economies.

As with other IEAs, since its adoption, the KP has received criticism from experts because of free-rider issues. Specifically, legally binding targets are applied to a limited number of nations, while excluding other major polluting countries, such as China and India. Moreover, the term "legally binding" is ambiguous. Article 18 of the KP briefly mentions that consequences for any case of non-compliance shall be discussed and determined by the parties and "shall be adopted by means of an amendment to this Protocol" (United Nations 1998). Thus, no punishment is clearly stated. In terms of competitiveness, the Kyoto commitments mean increased environmental policy stringency, which is expected to lead to a comparative disadvantage for pollution-intensive industries in these Annex B countries.

2.2 Industry of Environmental Goods

Facing the deteriorating environmental issues, the Organization for Economic and Co-operation Development (OECD)/Eurostat Informal Working Group, in its meeting in 1995, identified a group of products and services that can provide promising solutions. They are named "environmental goods", which consist of "activities which produce goods and services to measure, prevent, limit, minimize or correct environmental damage to water, air and soil, as well as problems related to waste noise and eco-systems" (OECD 1999).

The Working Group divides EGs into three categories: pollution management, cleaner technologies and products, and resource management (OECD 1999). Of all three groups, the pollution management group accounts for the majority of EGs. Products in pollution management group are categorized into six sub-groups with a target to a pollution type: air pollution control, wastewater management, solid waste management, remediation and cleanup of soil and water, noise and vibration abatement, and monitoring, analysis & assessment. While the products in the pollution management group aim to solve current

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[5] Details of the emission limitation or reduction commitment can be found at https://unfccc.int/kyoto_protocol.

[6] See https://unfccc.int/kyoto-protocol-html-version.

[7] From now, the terms "Annex B countries" and "Kyoto countries" are used interchangeably to indicate countries that have commitments in the KP.

[8] See https://unfccc.int/process/the-kyoto-protocol/the-doha-amendment.

pollution issues and damage in many environmental dimensions (e.g., water, air, noise), products in the two remaining groups focus on limiting and preventing emission via clean technology and energy as well as ensure natural resource sustainability.

Although the definition given by OECD is well-known, there are also other definitions and lists of EGs proposed by other organizations (Sugathan 2013). In fact, classification and definition of EGs is not universally agreed. In this analysis, I use a combination of the OECD and APEC Early Voluntary Sector Liberalization (EVSL) initiative lists. However, I restrict my attention to only products in the air pollution control (sub-category of the pollution management group) and the renewable energy plant (sub-category of the resource management group) as they provide direct solution to the air pollution and global warming issue.

2.3 Pollution Haven Hypothesis

In the debate about the relationship between environmental regulation and competitiveness, the pollution haven hypothesis posits that high environmental standards drive the reallocation of pollution-intensive industries to countries with less stringent regulations. In the case of the KP, it is highly likely that countries with binding target would reduce the production and exports of emission-intensive goods. Instead, they would have higher incentive to import those products from non-committed countries, which results in carbon leakage. There are a number of studies supporting this hypothesis (Aichele and Felbermayr 2012, 2013b, 2015). It is found that Kyoto commitment leads to a 13 to 14 per cent reduction in Annex B countries' exports, especially industries with high energy intensities (Aichele and Felbermayr 2013b). Similarly, by employing the gravity model and fixed-effects, Kim (2016) also reports supporting evidence for the negative effect of the KP on trade flows for G20 countries. Furthermore, there is an around 8 percent increase in the embodied carbon imports of the Annex B countries from non-Annex B countries, suggesting carbon leakage (Aichele and Felbermayr 2015).

In addition, this negative effect is documented in studies about other IEAs (Ederington et al. 2018; Besedeš et al. 2017). These two previous studies investigate all available IEAs and report a decrease in the trade of manufacturing sectors because of the ratification of IEAs. However, Ederington et al. (2018) further show that this effect is small and disappears in the long term. In fact, the decline in dirty-good exports is compensated for by an increase in exports of cleaner industries within the member countries. These studies suggest consistency in the competitiveness loss effect of IEAs in the manufacturing sectors. Yet the ambiguity of the impact persistence indicates that IEAs in general and the KP in particular might not necessarily lead to an overall negative effect on competitiveness.

Conversely, there are few studies on environmentally friendly products in the existing literature. Costantini and Crespi (2008) and Miyamoto and Takeuchi (2018) are the two most closely related studies for this paper. Focusing on the energy technology sector and 20 OECD members, Costantini and Crespi (2008) use the gravity model and demonstrate that environmental regulation is a significant source of comparative advantages.[9] Specifically, they provide evidence that the stringency of environmental regulations drives the export

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[9] The products in the analysis were from the two subcategories of the resources management group of EGs: (i) renewable energy plant and (ii) heat energy savings and management.

of renewable energy technology, using a number of proxies for environmental regulation.[10] While the effect of the KP is not directly considered in the research, the authors argue that they make implicit considerations of the role of the KP when studying the energy sectors, as the protocol provides an institutional framework favorable to technology diffusion.[11]

Although Miyamoto and Takeuchi (2018) investigate the effect of technological development (proxied by patent application counts) on the trade flow of solar and wind technology, they also control for environmental policies, which are the KP and feed-in-tariff and renewable portfolio standard variables. The results indicate a strong positive correlation between the protocol and trade in solar and wind technology. Unfortunately, since the KP serves as a control variable in this study, the estimation of this variable coefficient cannot be interpreted as causal. As a result, it is essential to have an overview of the impact of the KP on exports of not only manufacturing products but also environmentally friendly ones.

3 Empirical Strategy

3.1 Framework

To evaluate the effect of the KP on trade in EGs, I follow Aichele and Felbermayr (2013b) and choose the unit of analysis of an exporter– importer pair (denoted p, henceforth). As argued by Aichele and Felbermayr (2013b), finding a control for a country pair is more feasible and credible than for a country (e.g. it is difficult to find a comparable unit with the U.S.A). Even though, in this case, I construct the counterfactual for the treated unit, the construction relies on the control group, which contains mostly less-developed countries. Therefore, using the country pair as the analysis unit is also more appropriate. By considering the country pair unit, I can generate the model to similar frameworks in causal inference, as noted in Xu (2017). The functional form is written as:

$$Y_{pt} = \alpha_0 + \alpha_{pt} Kyoto_{pt} + \beta x'_{pt} + \lambda'_p f_t + \varepsilon_{pt} \tag{1}$$

where Y_{pt} denotes the bilateral exports of an exporter– importer pair p in year t; $Kyoto_{pt}$ is a dummy variable taking a value of 1 if the exporter of a country pair p has a Kyoto commitment in year t and 0 otherwise; x_{pt} is a $(k \times 1)$ vector of observed covariates, including the exporter's and importer's GDP and other bilateral gravity variables (i.e. regional trade agreement membership or common currency membership); β is a $(k \times 1)$ vector of parameters; α_{pt} is the heterogeneous treatment effect on country pair p in year t; f_t is a $(r \times 1)$ vector of unobserved common factors; λ_p is a $(r \times 1)$ vector of unknown factor loadings;[12] and ε_{pt} represents unobserved idiosyncratic shocks for pair p in year t.

As argued by Almer and Winkler (2017), the treatment period of the KP is not very clear. Most countries ratified the protocol during 2002 to 2003, yet it did not enter into

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[10] The proxies are carbon dioxide emissions, current environmental protection expenditures by both the public and private sectors, the percentage of revenues from environmental taxes in total revenues, and the public investment in environmental protection.

[11] Costantini and Crespi (2008) argue that carbon dioxide emissions is a proxy variable that partially represents countries' efforts to respect Kyoto abatement targets; however, the coefficient estimation shows no statistical significance.

[12] It is assumed that the factor component $\lambda'_p f_t = \lambda_{p1} f_{1t} + \lambda_{p2} f_{2t} + \ldots + \lambda_{pr} f_{rt}$ takes a linear and additive form

force until 2005.[13] However, according to the literature on the IEA, the ratification year can be considered the treatment period because, once countries ratify, they start making changes in their policies and implementation.[14] Therefore, I select the ratification year as the treatment period.

According to the functional form, α_{pt} is the coefficient of interest, representing the treatment effect. Let $Y_{pt}(1)$ and $Y_{pt}(0)$ be the outcome for a country pair p in year t when $Kyoto_{pt} = 1$ or $Kyoto_{pt} = 0$, respectively. Therefore, the treatment effect on treated pair p in year t is expressed as:

$$\alpha_{pt} = Y_{pt}(1) - Y_{pt}(0), t > T_0 \tag{2}$$

3.2 Generalized Synthetic Control

3.2.1 Description

To assess the effect of the Kyoto commitment on the bilateral export of EGs, I employ the GSCM proposed by Xu (2017). This method is based on the idea of the synthetic control method, developed by Abadie et al. (2010, 2015), such that the treated counterfactuals are synthesized by using the pre-treatment outcomes of treated units as benchmarks to select weights for control units and using cross-sectional correlations between treated and control units. In addition, it integrates the interactive fixed-effects (IFE) model proposed by Bai (2009).

The GSCM has a number of advantages over the popular DID and synthetic control approach. First, similar to the synthetic control method, it overcomes the issue with "parallel trend" assumption of the DID identification, which cannot be valid in many cases. By minimizing the difference between the treated and synthetic counterfactual in the pre-treatment period, it makes the comparison between the treated and synthetic control units transparent. Second, this method allows the analysis of multiple treated units and multiple treatment time periods, while the original synthetic control method can only perform one-by-one analyses. This is particularly useful when there are so many country pairs being analyzed, and Australia and Croatia receive treatment later than other countries.[15] Third, it provides classical standard errors to infer statistical significance, whereas the synthetic control method relies on comparing the estimates with the placebo treatment effects.[16]

However, the GSCM has three limitations that require researchers to be cautious during its application. First, since it is a data-driven approach, it is advised that the method should be applied to data with at least 10 pre-treatment periods and at least 40 control units (Xu 2017). Otherwise, the treatment effect will be biased. In this exercise, this should not be an issue, as the analysis period spans 1990 to 2012, with a treatment year of either

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[13] Australia and Croatia ratified in 2007, so the enforcement year for these two countries is also 2007.

[14] Ratification is used as a treatment period in the majority of Kyoto studies, such as Grunewald and Martinez-Zarzoso (2016); Almer and Winkler (2017).

[15] Aichele and Felbermayr (2013b) restrict their analysis period to 2007 and consider Australia an "untreated" country.

[16] The placebo studies are conducted by assigning one unit in the control group as "treated" and analyzing its effect with the remaining units in the control group. Theoretically, there should be no treatment effect found in these control units. Therefore, the treatment effect found in the actual "treated" unit is considered significant when it is larger than that of all control units.

2002 or 2005. Further, the number of control country pairs is much larger than 40. Second, excessive extrapolation resulting from no common factor loadings between the treated and control units may provide misleading results. A recommended solution to this issue is to check the overlap of the estimated factor loadings of both treated and control units (Xu 2017). Third, the method cannot accommodate complex data-generating processes, such as dynamic relationships between treatment, covariates and outcome, structural breaks, and multiple times of treatment and variable treatment intensity. As can be seen in the framework, in this study, these issues do not exist. Specifically, while there are different ratification years (2001 to 2004) among the Annex B countries, 2002 is the year in which the majority ratified the KP. In addition, there is no great difference between the 2002 to 2004 treatment intensity among countries (Maamoun 2019). In conclusion, the GSCM is a suitable method for this study.

3.2.2 Estimation Strategy

As stated in Eq. (2), the main issue of the treatment effect estimation is the counterfactual $Y_{pt}(0)$, which is not observed when the treated unit receives the treatment (i.e. the exporter ratifies the KP). Therefore, the core idea of the GSCM is to estimate the counterfactual of the treated pairs. Below is a brief description of the counterfactual estimation.[17]

Assuming the number of country pairs is $N = N_{tr} + N_{co}$, where N_{tr} and N_{co} are the number of treated and control units, respectively, the outcome of a pair from the control group can be written as:

$$Y_{pt} = X'_{pt}\beta + \lambda'_p f_t + \varepsilon_{pt}$$

Thus, the outcome of the counterfactual after the combination of all control pairs is

$$Y_{co} = X_{co}\beta + F\Lambda'_{co} + \varepsilon_{co}$$

where Y_{co} and ε_{co} are (T x N_{co}) matrices; X_{co} is a three-dimensional matrix (T x N_{co} x k); and Λ_{co} is a (N_{co} x r) matrix. There are two constraints required to identify β, F, and Λ_{co}: all factors are normalized and are orthogonal to each other.

The construction of the counterfactual $\hat{Y_{pt}}(0)$ contains three steps. The first step is the estimation of an IFE model using only the control group data and obtaining $\hat{\beta}$, $\hat{F}$, and $\hat{\Lambda_{co}}$:

$$(\hat{\beta}, \hat{F}, \hat{\Lambda_{co}}) = \text{argmin}_{\tilde{\beta}\tilde{F}\tilde{\Lambda}_{co}} \sum_{p \in C}(Y_p - X_p\tilde{\beta} - \tilde{F}\tilde{\lambda}_p)'(Y_p - X_p\tilde{\beta} - \tilde{F}\tilde{\lambda}_p)$$

s.t. $\tilde{F}'\tilde{F}/T = I_r$ and $\tilde{\Lambda}_{co}'\tilde{\Lambda}_{co} = $ diagonal

In the second step, factor loadings for each treated unit are estimated by minimizing the mean squared error of the predicted treated outcome (MSPE) in pretreatment periods:

$$\hat{\lambda}_p = \text{argmin}_{\tilde{\lambda}_p}(Y^0_p - X^0_p\hat{\beta} - F^{\hat{0}}\tilde{\lambda}_p)'(Y^0_p - X^0_p\hat{\beta} - F^{\hat{0}}\tilde{\lambda}_p)$$
$$= (F^{\hat{0}'}\hat{F}0)^{-1}F^{\hat{0}'}(Y^0_p - X^0_p\hat{\beta}), p \in \mathcal{T}$$

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[17] Further details can be found in Xu (2017).

where $\hat{\beta}$ and $\hat{F}^0$ are from the first-step estimation and the superscripts "0s" represent the pre-treatment periods, and $\mathcal{T}$ denotes the set of units in the treatment group. The third step is to calculate treated counterfactuals based on $\hat{\beta}$, $\hat{F}$, and $\hat{\lambda}_p$:

$$\hat{Y}_{pt}^0 = x'_{pt}\hat{\beta} + \hat{\lambda}_p{}'\hat{f}_t$$
$$p \in \mathcal{T}, t > T_0$$

The ATT_t is hence estimated as $\hat{ATT}_t = \frac{1}{N_{tr}}\sum_{i \in \mathcal{T}}[Y_{pt}(1) - \hat{Y_{pt}(0)}]$ for $t > T_0$.

4 Data

Bilateral EG trade data at the product level during the period 1990 to 2015 come from the UN Comtrade (2018) database.[18] However, the analysis period is restricted to 1990 to 2012. The first commitment period of the KP ended in 2012. After that, there was an amendment; however, this was not validated until October 2020 and it remains unclear whether the KP is still effective. As a result, I select 2012 as the end year of the analysis period. As stated in the introduction, this study includes products in the air pollution control, environmental monitoring, cleaner technology, and renewable energy subgroups. Together, these subgroups comprise 86 of 173 six-digit HS EGs listed in both the OECD list and APEC list. Information on the Annex B countries included in the dataset and their ratification years is available in Table 8.[19] The definitions and data sources of the other variables are provided in Table 9.

Table 1 provides insights of the key players in the export market of EGs. In particular, the US, Germany and Japan are the top exporters, accounting for 45% of world trade over the period 1990–2012. Besides, most countries in the list of top ten exporters are countries with Kyoto commitments. In fact, the top ten Annex B exporters export nearly half of the total world trade during the same period. With regards to imports, many Annex B countries are also among the top importers. However, it is worth noting that several top Annex-B importers are developing countries, especially China and Mexico. This observation will be discussed later in Mechanism section.

Many country pairs have missing values for a number of periods in the original data. As discussed previously, the method works well with a minimum of 10 years in the pre-treatment period. Therefore, I first restrict the dataset to country pairs with non-missing values for at least 20 years out of 26 years (the raw data are available from 1990–2015).[20] During the analysis, the dataset is restricted to the period 1990–2012. In addition, any pairs with fewer than 10 period observations are automatically dropped during the analysis. The final dataset consists of 136 exporters and 95 importers, representing 3,049 country pairs and a 23-year period from 1990 to 2012. Of these, 907 exporter– importer pairs commit to the KP, accounting for 29.7% total country pairs in the sample. The total nominal trade value of the final sample over the period 1990–2012 is 3,250 billion USD, which comprises more

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[18] Trade value is expressed in current USD, so it is deflated using the United States Consumer Price Index.
[19] Source: https://treaties.un.org/Pages/ViewDetails.aspx?src=TREATY&mtdsg_no=XXVII-7-a&chapter=27&clang=_en.
[20] This restriction will help speed up the analysis, as a larger unbalanced panel will significantly slow the process. Note that the method cannot execute if there are observations with missing values in the covariates, so the sample is also restricted to all observations with no missing values in the covariates.

than 76% of total value in the original data.[21] In addition, exports from Kyoto countries in the final data value about 2,080 billion USD in total, which comprises roughly 85% of total values of exports from Annex B countries in the original data over the period 1990–2012.[22]

As briefly discussed in Sect. 2, the Doha Amendment was adopted by the end of 2012, and the parties were required to ratify this amendment again. However, the number of parties submitting their instrument of acceptance did not meet the requirement (at least 144) until the end of 2020. Therefore, these issues might affect the consistency of the treatment (i.e. the Kyoto commitments) because of unobserved factors. Given that the methodology cannot accommodate complex data-generating processes (DGPs), extending the sample period beyond 2012 might result in biased estimation.[23]

As previously discussed, there was a steady increase in the world trade of EGs during the early 2000s, which was the period in which most countries ratified the protocol (Fig. 1). Therefore, I expect a correlation between the Kyoto commitment and trade in EGs. Moreover, there was a difference in the change in bilateral trade level between the exports from Annex B and non-Annex B countries.

In addition, the descriptive statistics, in Table 2, demonstrate that the EG export value of the treated country pairs is larger than that of the control ones. Moreover, the pairs with Annex B countries as exporter have higher GDP and GDP per capita, use more energy, tend to participate in free trade agreements and the EU, and are more likely to use the common currency. There is not a significant difference in the tendency to be a WTO member between two groups.

5 Results and Discussion

5.1 Main Results

Table 3 presents the baseline results. Column (1) includes basic gravity variables as covariates, while Column (2) includes additional variables, such as the per-capita GDP of the exporter and importer, the energy intensity of the trading pairs,[24] and dummies for the European Union (EU) membership and WTO membership of the trading pair.[25] Additional variables are included to control endogeneity resulting from voluntary selection into the KP or non-random treatment. Countries with Kyoto commitments are chosen based on their previous industrialization, and could also strategically choose to ratify the KP to boost

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[21] The total nominal trade value of the original data in the same period is 4,270 billion USD.

[22] The export value from Annex B countries in the raw data is about 2,450 billion USD.

[23] In the robustness check, I extend the analysis to 2015, as some might argue that the Doha Amendment has not yet been effective. It is possible that the Doha Amendment has little effect on the original Kyoto commitments. While the data are now available until 2017, I again restrict the analysis until 2015, as the Paris Agreement was adopted in 2015. The agreement could be regarded a structural break, so the method cannot accommodate the DGP in this case.

[24] Similar to Aichele and Felbermayr (2013b), the energy intensity of the pair is the difference between the energy intensity of the exporter and importer.

[25] Note that for all analyses in this paper, the last year for Romania is dropped. The reason for this exclusion lies in the fact that Romania was the first country to ratify the KP in 2001, while the ratification year for most remaining countries was 2002. Given that the method scales the ratification year as 0 for all countries, only Romania has the longest post-treatment period. Hence, Romania is the only treated country in the final period, which might result in exaggerating the estimation of the counterfactual average at this period.

Table 1 Top 10 largest importers and exporters over the period 1990–2012

Ten largest exporters	Value of exports (billion USD)	% of world trade	Ten largest Annex B exporters	Value of exports (billion USD)	% of world trade
Switzerland	100	2.4%	Spain	51	1.2%
Mexico	101	2.4%	Sweden	67	1.6%
Netherlands	106	2.5%	Belgium	74	1.7%
Italy	179	4.2%	Switzerland	100	2.4%
France	193	4.6%	Netherlands	106	2.5%
United Kingdom	195	4.6%	Italy	179	4.2%
China	320	7.5%	France	193	4.6%
Japan	457	10.8%	United Kingdom	195	4.6%
Germany	676	15.9%	Japan	457	10.8%
USA	758	17.9%	Germany	676	15.9%
Total	3,085	73%	**Total**	2,098	49.5%
Ten largest importers	Value of imports (billion USD)	% of world trade	Ten largest non-Annex B importers	Value of imports (billion USD)	% of world trade
Mexico	127	3.0%	Brazil	62	1.5%
Italy	160	3.8%	Malaysia	62	1.5%
Canada	161	3.8%	Thailand	69	1.6%
South Korea	167	3.9%	Hong Kong	78	1.8%
United Kingdom	170	4.0%	Singapore	94	2.2%
Japan	181	4.3%	Mexico	127	3.0%
France	192	4.5%	Canada	161	3.8%
China	300	7.1%	South Korea	167	3.9%
Germany	407	9.6%	China	300	7.1%
USA	564	13.3%	USA	564	13.3%
Total	2,429	57.3%	**Total**	1,684	39.7%

the reputation of their EG quality, or not ratify at all (e.g. the U.S.A). In theory, endogeneity should influence the counterfactual; thus, using the synthetic counterfactual should control part of the issue (Billmeier and Nannicini 2013). In addition, the unobservable confounders, capturing the inherent differences that potentially result from non-random treatment, could also alleviate the endogeneity. Nevertheless, to ensure the robustness of the results, I include additional covariates that could reflect the difference between the treated group and control group. These variables are chosen based on the arguments that could influence self-selection into the KP, as discussed in Aichele and Felbermayr (2013b).

Table 2 Summary Statistics

Variables	Total sample				
	N	mean	sd	min	max
Ln($ExportValue_{pt}$)	71,826	14.18	3.191	0.723	22.96
$Kyoto_{pt}$	71,826	0.168	0.374	0	1
Ln(GDP_{it})	71,826	26.32	1.848	19.18	30.44
Ln(GDP_{jt})	71,826	26.29	1.976	19.83	30.44
Ln($GDPC_{it}$)	71,826	9.330	1.319	5.087	11.43
Ln($GDPC_{jt}$)	71,826	9.420	1.336	5.208	11.43
FTA_{pt}	71,826	0.224	0.417	0	1
$Currency_{pt}$	71,826	0.0236	0.152	0	1
$ENERGY_{pt}$	71,826	0.237	4.196	-30.99	46.60
EU_{pt}	71,826	0.0474	0.212	0	1
WTO_{pt}	71,826	0.838	0.368	0	1
	Pairs with Annex B countries as exporter				
	N	mean	sd	min	max
Ln($ExportValue_{pt}$)	22,598	15.64	2.794	0.723	22.96
$Kyoto_{pt}$	22,598	0.533	0.499	0	1
Ln(GDP_{it})	22,598	27.13	1.114	24.14	29.42
Ln(GDP_{jt})	22,598	26.31	1.785	20.22	30.44
Ln($GDPC_{it}$)	22,598	10.35	0.763	7.431	11.43
Ln($GDPC_{jt}$)	22,598	9.432	1.259	5.705	11.43
FTA_{pt}	22,598	0.311	0.463	0	1
$Currency_{pt}$	22,598	0.0541	0.226	0	1
$ENERGY_{pt}$	22,598	0.290	4.106	-19.45	23.17
EU_{pt}	22,598	0.136	0.342	0	1
WTO_{pt}	22,598	0.831	0.375	0	1
	Pairs with non-Annex B countries as exporter				
	N	mean	sd	min	max
Ln($ExportValue_{pt}$)	49,228	13.51	3.138	1.519	22.96
$Kyoto_{pt}$	49,228	0	0	0	0
Ln(GDP_{it})	49,228	25.95	1.993	19.18	30.44
Ln(GDP_{jt})	49,228	26.28	2.058	19.83	30.44
Ln($GDPC_{it}$)	49,228	8.862	1.255	5.087	11.19
Ln($GDPC_{jt}$)	49,228	9.414	1.370	5.208	11.43
FTA_{pt}	49,228	0.185	0.388	0	1
$Currency_{pt}$	49,228	0.00959	0.0974	0	1
$ENERGY_{pt}$	49,228	0.213	4.236	-30.99	46.60
EU_{pt}	49,228	0.00693	0.0829	0	1
WTO_{pt}	49,228	0.842	0.365	0	1

Author's calculation from UN Comtrade (2018)

Table 3 The effect of KP on trade in environmental goods

	(1)	(2)
ATT	0.299***	0.293***
	(0.065)	(0.063)
Ln(GDP_{it})	1.629***	1.995***
	(0.142)	(0.243)
Ln(GDP_{jt})	1.280***	1.135***
	(0.145)	(0.309)
FTA_{pt}	0.076*	0.064
	(0.045)	(0.045)
$Currency_{pt}$	1.034***	0.892***
	(0.193)	(0.204)
Ln($GDPC_{it}$)		-0.324
		(0.204)
Ln($GDPC_{jt}$)		0.055
		(0.339)
$Energy_{pt}$		0.027**
		(0.012)
EU_{pt}		0.318*
		(0.187)
WTO_{pt}		0.173***
		(0.058)
MSPE	0.782	0.781
No. treated	907	907
No. control	2,142	2,142
Unobserved factors	1	1

Notes. The period of analysis is 1990–2012. Standard errors, in parentheses, are based on parametric bootstraps of 1000 times. ***, **, * Significance at 1%, 5%, and 10%
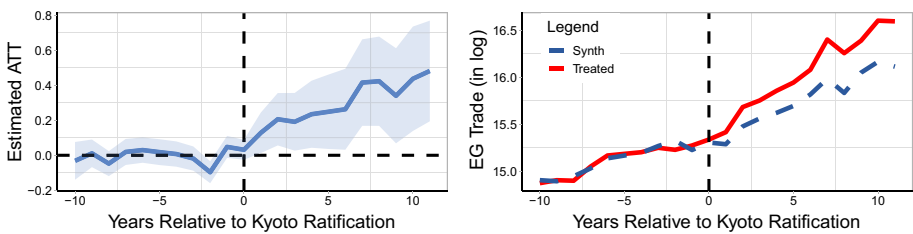

Fig. 3 Main result *Notes.* This figure plots estimated ATT (on the left) and trend of treated and counterfactual averages (on the right). Shaded areas are 95% confidence interval based on parametric bootstraps of 1000 times

However, the results of the two columns are very similar; thus, further analysis includes only the basic covariates. The cross-validation scheme finds one unobservable factor.[26] According to Xu (2017), the unobservable factors found are usually not interpretable. However, as the unobserved factor in these panel data represents the cross-section dependence, it exhibits the correlation among countries. A plot of the factor is displayed in Fig. 10. Thus, conditioning on the additive fixed-effects and unobservable factor, the results show that the Kyoto commitments result in a 29 to 30% increase in the export of EGs, compared with the scenario of "no Kyoto."

Figure 3 presents the plot of treated and counterfactual averages and the dynamics of the estimated ATT. For each figure, the x-axis represents the time relative to treatment (i.e. time scaled to 0 at the time of treatment). The vertical line at time 0 demonstrates the start of the treatment. As can be seen, the treated and counterfactual averages match quite well in the pre-treatment period, and diverge once the treatment starts (i.e. countries ratify the KP). The estimated ATT plot exhibits a constant increase in the export of EGs following the ratification of the protocol.

It is worth noting that the results presented in this paper can only explain the impact on the intensive margin of trade although discussion on the extensive margin would be desirable to have a more complete overview of the Kyoto impact. The GSCM requires the bilateral trade data in the pre-treatment period (i.e. before ratification of the KP) to construct the synthetic control unit. As a result, the estimation can be done on existing trading pairs.

Moreover, it is important to note the coefficient of the exporter's and importer's GDP. I estimate a larger export elasticity with respect to the exporter's GDP than with respect to the importer's GDP, which is contrary to what is usually observed in most gravity trade studies. An explanation of this outcome is provided by Feenstra et al. (2001) in the case of trading differentiated goods, with this observation termed the "home-market effect" (Krugman 1980). As established in Feenstra et al. (2001), high demand for goods produced in a large country leads to more entry of firms and more product variety. Eventually, the product supply is greater than the demand in a larger country, so the exports of the differentiated goods exceed imports (i.e. positive net export).

In addition, the coefficient of free trade dummy is not statistically significant, although it is positive. This study focuses on a group of products, and trade liberalization of EGs is still under negotiation.[27] As noted in Sect. 2, the APEC 2012 Vladivostok Declaration is the most concrete international agreement on EG trade to date. However, this agreement also applies to a small number of EGs. Therefore, a strong correlation between free trade agreements and trade of EGs is not observed.

5.2 Robustness Checks

To ensure the robustness of my results, I perform several sensitivity analyses. The results of all robustness checks are presented in Table 4. The plots of treated and counterfactual averages and estimated ATT for each robustness check are presented in Figs. 4 and 5. *Treatment period*—Although most countries ratified the KP by 2003, it did not enter into

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[26] Given that the exact number of factors to be included in the model is unknown, the cross-validation procedure is designed to select the number of factors before the causal effect estimation. Basically, the procedure chooses the number of factors that minimizes the mean square prediction error (MSPE) from a given set of numbers (i.e. 0 to 5 in this case).

[27] https://www.wto.org/english/tratop_e/envir_e/ega_e.htm

Table 4 Robustness check

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
ATT	0.185***	0.422***	0.289***	0.309***	0.197**	0.612***	0.314***	0.375***	0.290***	0.299***
	(0.040)	(0.074)	(0.074)	(0.074)	(0.086)	(0.110)	(0.070)	(0.071)	(0.066)	(0.070)
$Ln(GDP_{it})$	1.629***	1.747***	1.974***	1.629***	1.205***	2.257***	1.597***	1.646***	1.514***	1.629***
	(0.142)	(0.120)	(0.180)	(0.144)	(0.147)	(0.169)	(0.148)	(0.152)	(0.155)	(0.149)
$Ln(GDP_{jt})$	1.280***	1.302***	1.259***	1.279***	0.876***	0.944***	1.295***	1.319***	1.313***	1.280***
	(0.148)	(0.127)	(0.193)	(0.151)	(0.027)	(0.192)	(0.160)	(0.147)	(0.152)	(0.153)
FTA_{pt}	0.076*	0.063	-0.103	0.076*	0.088***	0.117*	0.071	0.061	0.069	0.076*
	(0.046)	(0.041)	(0.067)	(0.045)	(0.048)	(0.060)	(0.047)	(0.050)	(0.044)	(0.045)
$Currency_{pt}$	1.034***	0.803***	-	1.034***	0.802***	1.517***	1.034***	1.023***	1.000***	1.034***
	(0.189)	(0.211)		(0.187)	(0.228)	(0.375)	(0.194)	(0.195)	(0.199)	(0.203)
$Ln(ElectricalTrade_{pt})$					0.212***					
					(0.009)					
MSPE	0.818	0.782	0.890	0.563	0.905	1.091	0.771	0.738	0.782	0.782
No. treated units	1,619	907	574	768	601	756	959	852	907	907
No. control units	2,142	2,142	1,231	2142	1,706	1,356	2,058	2,142	2,049	2,142
Unobserved factors	1	1	1	1	1	1	1	1	1	1

Notes. Standard errors, in parentheses, are based on parametric bootstraps of 1000 times unless noted. ***, **, * Significance at 1%, 5%, and 10%

(1) Treatment period: Enforcement year (2007 for Australia and Croatia; 2005 for all other countries)

(2) The sample period is 1990–2015

(3) Only trade to non-Kyoto countries are analyzed

(4) Exports from Eastern European countries, Russia and Ukraine are excluded

(5) Trade value of manufacture of computer, electrical, and optical products is included as an additional covariate

(6) The sample is restricted to trade of renewable energy products

(7) Canada is included in the treated group

(8) The sample period is 1992–2012

(9) The sample excludes USA as exporter

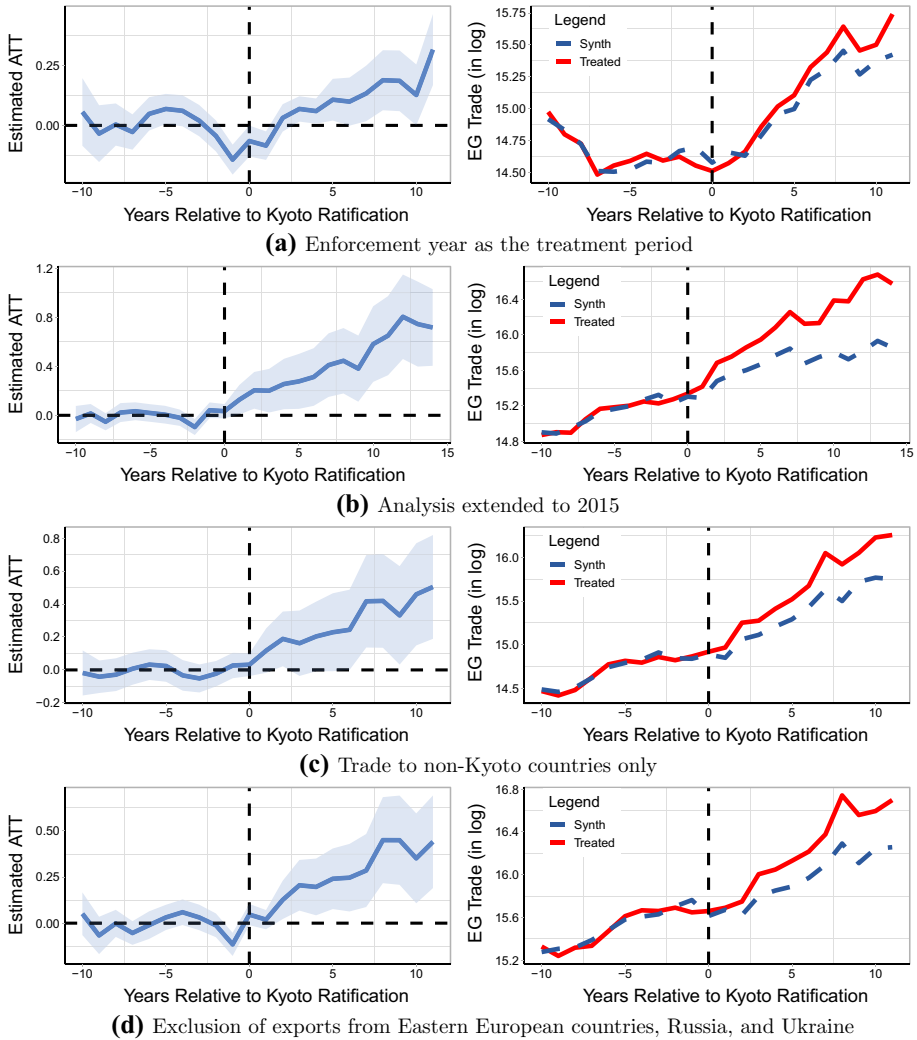(10) The sample excludes DEU as exporter

(a) Enforcement year as the treatment period

(b) Analysis extended to 2015

(c) Trade to non-Kyoto countries only

(d) Exclusion of exports from Eastern European countries, Russia, and Ukraine

Fig. 4 Robustness checks. *Notes.* This figure plots estimated ATT (on the left) and trend of treated and counterfactual averages (on the right). Shaded areas are 95% confidence interval based on parametric boot-straps of 1000 times

force until 2005.[28] Several studies use the enforcement year as the treatment period, such as Maamoun (2019). Therefore, in the first robustness check, I change the treatment period to the enforcement year: 2007 for Australia and Croatia, and 2005 for all other countries. Despite the statistical significance, the ATT is reported as 18.5% in Column (1), which is smaller than the estimation in the main result.

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[28] Details of the ratification year can be found in Table 8.

(a) Trade of manufacture of computers, electrical, and optical products is included as a covariate

(b) Sample restricted to trade of renewable energy products

(c) Canada included in the treated group

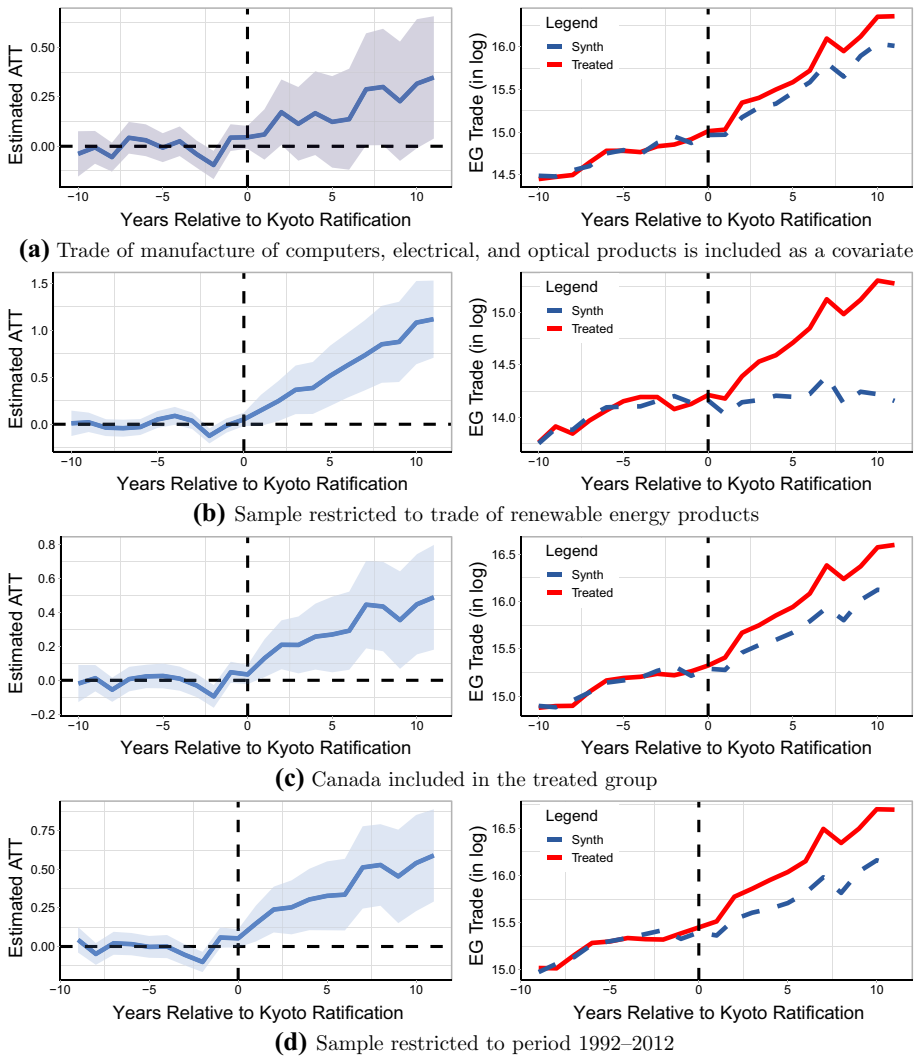**(d)** Sample restricted to period 1992–2012

Fig. 5 Robustness checks (continued) *Notes.* This figure plots estimated ATT (on the left) and trend of treated and counterfactual averages (on the right). Blue (Grey) shaded areas are 95% (90%) confidence interval based on parametric bootstraps of 1000 times

Figure 4a exhibits the plots of treated and counterfactual average and estimated ATT. As can be seen, there is an increase in export even before the assigned treatment year. Therefore, by using the enforcement year as the treatment period, the estimated effect is much smaller than the baseline. This finding indicates that countries already prepared actions immediately after their ratification.

Period extension to 2015—Even though, after 2012, there was the Doha Amendment to the KP, but this amendment did not enter into force until October 2020. Therefore, one can

argue that the KP should still be valid. Thus, I extend my analysis period to 2015, and the estimated ATT (0.422) is larger than the baseline result. This is expected, as it accounts for the additional years. This indicates that the effect of the KP could persist after its first commitment period. However, this interpretation must be applied with caution, as the confidence interval in the ATT plots, shown in Fig. 4b, is quite large when years beyond 2012 are considered.

Removal of trade to Kyoto countries—The analysis thus far is conducted on a sample including export to both Kyoto and non-Kyoto countries. However, there may be concern that the protocol could affect the imports of Annex B countries, thereby biasing the main results. Therefore, I restrict the sample to export to countries without Kyoto commitments only (i.e. only export from either Annex B or non-Annex B countries to non-Annex B countries).[29] The estimated ATT, in Column (3), is reported as 0.289, which is slightly smaller than the baseline results. This implies that the observed result above is not driven by the effect of KP on the import of Annex B countries.

Removal of exports from Eastern European countries, Russia, and Ukraine—Some countries, such as Eastern Europe, Russia and Ukraine, are known to have no obligations or limited real commitments in reducing the emissions. This raises a concern in understanding the true effect of the KP as well as the mechanism underlying the reported result. That is, the poor commitment by these countries could result in a reduced treatment effect with their inclusion in comparison with the effect with exclusion of them. Therefore, this part performs analysis that excludes exports from Eastern European countries (in this study, it includes Bulgaria, Czech Republic, Poland, and Romania), Russia, and Ukraine.

The plots show high similarity to the ones reported in the main result. The estimated ATT, reported in Column (4), has a slight change in magnitude (0.309). This is reasonable as Eastern European countries and Former Soviet Union countries comprise a small part of all treated countries in the analysis sample. However, the increase in magnitude confirms that inclusion of these countries leads to the estimation bias.

Trade of manufacture of computers, electrical and optical products included as an additional covariate—Although the country pairs fixed effect can capture many time-invariant characteristics, it is essential to test the robustness by controlling for other time-varying features. In the section of main results, I added additional variables such as the energy intensity, the WTO membership and EU membership. The result is quite robust and similar to the main one. In this part, I perform another robustness check by including trade in non-environmental and non- (or low) emission goods as a proxy for time-varying features. According to the statistics for EU 28 countries in 2013, manufacture of computer, electronic and optical products is the industry with the least emission intensity among all tradable ones.[30] As a result, I include trade value of this industry (in log) as one of the covariates.[31]

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[29] The covariate, $Currency_{pt}$, is not included in the analysis due to almost no variation.

[30] See https://ec.europa.eu/eurostat/databrowser/view/ENV_AC_AINAH_R2__custom_1234643/default/table?lang=en

[31] Trade data (in HS code 85 and 90) come from UN Comtrade. Trade values recorded in HS code 85 (i.e. Electrical machinery and equipment and parts thereof) and 90 (i.e. Optical, photographic, cinematographic, measuring, checking, precision, medical or surgical instruments and apparatus; clocks and watches; musical

The plots of this robustness check display a similar pre-treatment fit compared to most results. However, the shaded area in the post-treatment period is much larger. Despite a smaller magnitude (0.197), shown in Column (5), compared to the baseline result, the ATT remains statistically significant. Together, this indicates robustness of the results even when more time-varying characteristics are captured.

Trade of renewable energy products as dependent variable—The goal of the KP is to combat the climate change, which is driven by increasing concentration of greenhouse gas in the atmosphere. Thus, it makes sense that renewable energy products should be promoted more after the KP. However, this paper also includes pollution control products in the analysis, which may raise concern about the validity of this inclusion. While climate change and air pollution appear to be different problems, they are actually correlated with each other, according to UN Environment Programme.[32] For example, once landing on ice and snow, particular matter can darken them slightly and eventually result in less sunlight being reflected back into space. This would contribute to global warming.

Nevertheless, as renewable energy goods are usually perceived as key products in the battle against climate change, this part conducts one additional analysis on sample restricted to trade of renewable energy products. Estimation of this robustness check is presented in column (6) of Table 4. The corresponding plots of treated and countefactual average, and estimated ATT are demonstrated in Fig. 5b. The results show a positive and significant impact on trade of renewable energy products, and the magnitude of this effect is even larger (more than 60% relative to "no-Kyoto" scenario).

Canada as a treated country—Canada originally ratified the protocol, but then decided to withdraw at the end of 2012.[33] Given that the analysis period in this study runs from 1990 to 2012, Canada can still be regarded one of the Annex B countries.[34] Therefore, I now consider any trading pairs with Canada as an exporter as a "treated" country. The result is reported in Column (7) of Table 4. As can be seen, there is almost no difference in the estimated ATT (0.314) relative to the main results. Moreover, the plots, as demonstrated in Fig. 5c, are very similar to the baseline results. The results suggest that the reported effect is not affected by Canada's membership status.

Sample period of 1992 to 2012—Given that a few countries retrospectively reported trade data using the 1992 HS before 1992, Column (8) estimates the sample for 1992 to 2012. In the previous analysis, the trade value in the first pre-treatment period is very low, which affects the synthesis of the counterfactuals. Thus, dropping the years 1990 and 1991 results in larger estimation, as shown in Column (8) of Table 4. Despite the larger value of the estimated ATT (roughly 37.5%), it is generally not much different from the baseline finding.

Footnote 31 (continued)

instruments; parts and accessories thereof) match the definition of this industry best. Note that EGs in this study that fall in category of HS 85 and 90 are excluded from the data.

[32] See https://www.unep.org/news-and-stories/story/air-pollution-and-climate-change-two-sides-same-coin

[33] See https://unfccc.int/files/kyoto_protocol/compliance/enforcement_branch/application/pdf/cc-eb-25-2014-2_canada_withdrawal_from_kp.pdf.

[34] Almer and Winkler (2017) use Canada as a treated country in their analysis of the KP's effectiveness.

Exclusion of top exporters—The statistics show that the U.S.A and Germany are the top two exporters in the market of EGs. While both countries signed the agreement, the U.S.A never ratified the KP; thus, it is considered "untreated." It is possible that both countries could affect the estimated effect. Therefore, I re-conduct the analysis excluding either the U.S.A or Germany as the exporter from the sample. The results are reported in Columns (9) and (10) of Table 4. The graphs of synthetic counterfactuals and ATT over time can be found in Figs. 11 and 12.

The estimated ATT in both analyses are quite similar to each other and the main result (roughly 30% increase). This finding implies that the reported effect is not driven by the top exporters. Further, this also suggests that the GSCM performs well in developing suitable counterfactuals with the adjusted control group.

5.3 Case Study: Germany and Japan

Even though the model (1) contains unit and time fixed-effects, which can control for time-invariant characteristics of trading pairs and time trend, the difference between exporters (i.e. Annex B countries) and importers (i.e. non-Annex B countries, especially those less developed ones) over time can be the confounding factors leading to the significant coefficients reported above. Some robustness checks have also attempted to control for these time-variant features of trading pairs, but it might not capture all of them. Therefore, in this section, I study the impact of the KP on the total export values (i.e. exports to the whole world). In addition, to isolate effect of the KP on import, I conduct two separate analyses by restricting to two groups of data: export flows to Annex B countries and export flows to non-Annex B countries.

As displayed in Table 1, the values of exports of the top ten largest Annex B exporters comprise approximately half of the total world trade. Notably, of all ten countries, Germany and Japan are the two key players with the total values of exports accounting for about 27% of world trade. Therefore, I focus my analyses on Germany and Japan. Unlike the main analysis, I examine each country individually. The framework used to study the effect of the KP is very similar to model (1), but the unit of analysis is now at the country level.

$$Y_{it} = \gamma_0 + \gamma_{it} Kyoto_{it} + \gamma_1 X'_{it} + \lambda'_t f_t + \epsilon_{it} \tag{3}$$

where Y_{it} is export value of a country i in year t to Annex B countries (or to non-Annex B countries); $Kyoto_{it}$ is a dummy variable indicating whether country i has Kyoto commitment in year t. In the spirit of the gravity model, I include common variables in the vector of observed covariates X_{it}: country i's GDP, GDP per capita and population, energy intensity, and WTO membership dummy.[35]

ATT plots and plots of treated versus synthetic unit are shown in Fig. 6. The plots demonstrate that the treated unit and its counterfactual barely match each other in the pre-treatment period, which proves how difficult it is to develop the suitable counterfactual using the trade data at the unilateral level. According to Abadie et al. (2015), SCM should only be used if there is a good pre-treatment fit. Therefore, no conclusion can be drawn regarding the effect of the KP on export flow using GSCM.

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[35] GDP, GDP per capita and population are used as predictors in the SCM in Verevis and Üngör (2021), which is also a trade-related paper

(a) Sample restricted to export flow to Annex B countries

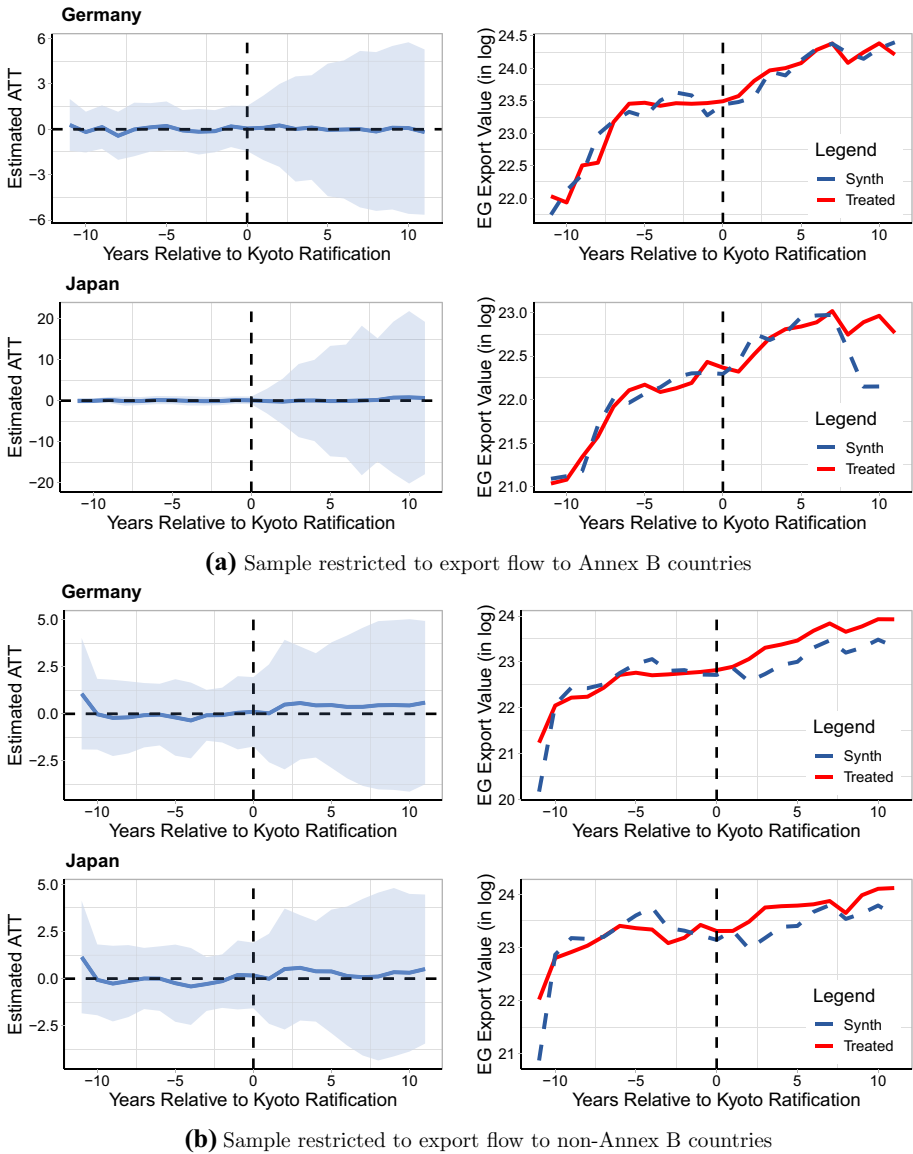**(b)** Sample restricted to export flow to non-Annex B countries

Fig. 6 Effect of the KP on exports using GSCM. *Notes.* This figure plots yearly treatment effect (on the left) and trend of export values (in log) on treated countries (Germany and Japan) against its synthetic control (on the right) using GSCM. Shaded areas are 95% confidence interval based on parametric bootstrap of 1,000 times

In order to find the appropriate counterfactuals for Germany and Japan, I further employ another recently developed method, which is augmented SCM (ASCM) by Ben-Michael et al. (2021). The core concept of ASCM is still to develop a synthetic control unit that resembles the treated unit as closely as possible in the pre-treatment period. Unlike the
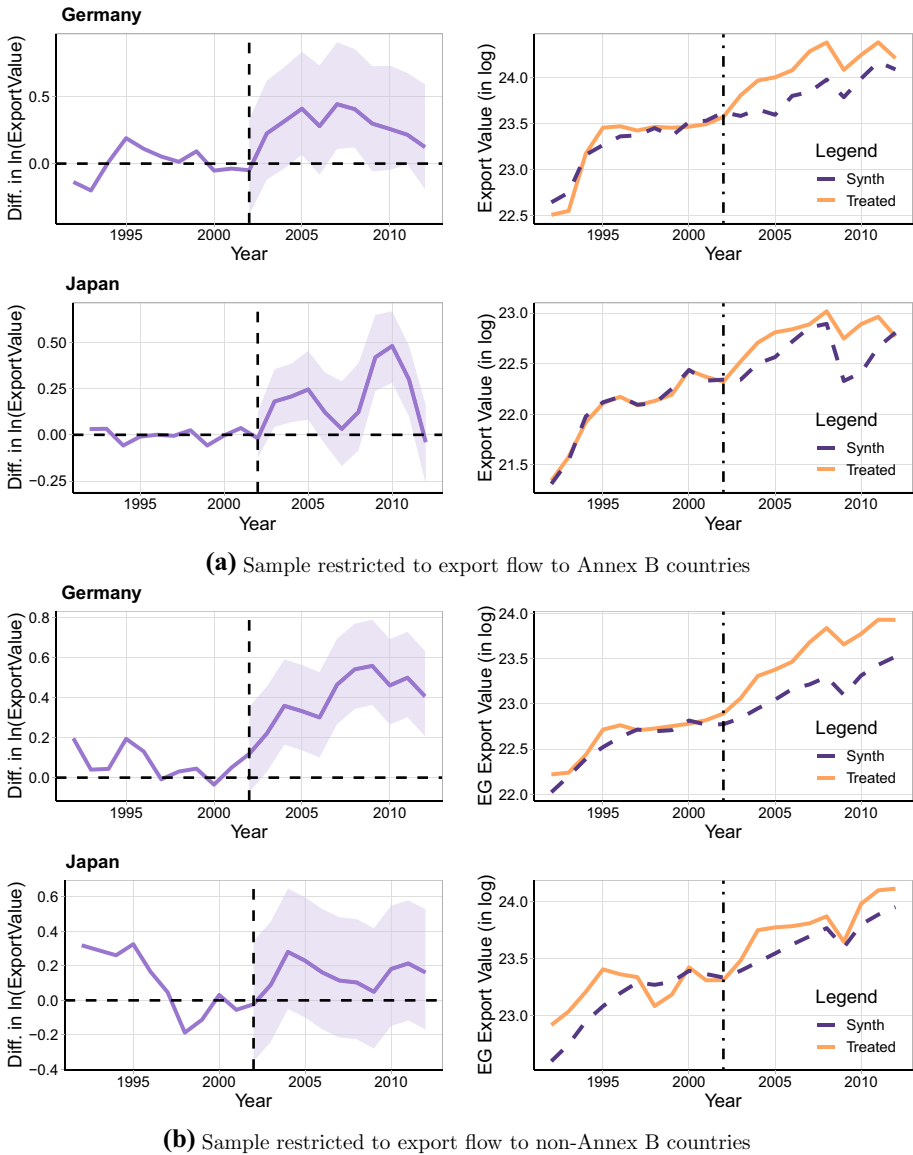
(a) Sample restricted to export flow to Annex B countries

(b) Sample restricted to export flow to non-Annex B countries

Fig. 7 Effect of the KP on exports using ridge SCM. *Notes.* This figure plots yearly treatment effect (on the left) and trend of export values (in log) on treated countries (Germany and Japan) against its synthetic control (on the right) using ridge SCM. Shaded areas are 95% confidence interval based on jackknife+ approach in Barber et al. (2021)

classical SCM, ASCM augments ridge regression to relax the assumption that weights must be non-negative. Therefore, it allows a certain amount of extrapolation and eventually enhances the pre-treatment fit. Simultaneously, the ridge regression also penalizes over

Table 5 Yearly treatment effect on the treated countries (Germany and Japan)

	Sample	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
Germany	Export flow to Annex B	-0.049	0.224	0.315	**0.408**	0.279	**0.442**	**0.405**	0.298	0.257	0.214	0.122
		(0.181)	(0.188)	(0.192)	(0.195)	(0.207)	(0.202)	(0.187)	(0.199)	(0.198)	(0.173)	(0.199)
Japan		-0.019	**0.180**	**0.207**	**0.245**	0.122	0.032	**0.124**	**0.419**	**0.480**	**0.299**	-0.040
		(0.063)	(0.080)	(0.081)	(0.095)	(0.099)	(0.117)	(0.120)	(0.105)	(0.099)	(0.097)	(0.108)
Germany	Export flow to non-Annex B	0.118	**0.220**	**0.359**	**0.332**	**0.301**	**0.465**	**0.541**	**0.559**	**0.461**	**0.499**	**0.406**
		(0.109)	(0.109)	(0.109)	(0.109)	(0.109)	(0.109)	(0.109)	(0.109)	(0.109)	(0.109)	(0.109)

Notes. Standard errors (in parentheses) from ridge SCM are calculated using jackknife+ approach by Barber et al. (2021). Estimates in bold imply statistical significance at 5% level

excessive extrapolation to avoid the danger of overfitting.[36] Besides, ASCM also provides statistical inference, which is a missing feature in the standard SCM. Both GSCM and ASCM are new developments in the growing literature on causal inference method. GSCM belongs to the branch of outcome modelling while ASCM is considered a hybrid method of matching and outcome modeling (Liu et al. 2020). To make the results comparable, I include the same variables used in the GSCM as the predictors in the ASCM. Yet I also include lagged value of the dependent variable, which is a common practice of the standard SCM. I includes average of lags of all pre-treatment periods as there is no agreed criteria to choose which pre-treatment outcome to be included (Ferman et al. 2020).

Following Almer and Winkler (2017), I first restrict the donor pool to high income and upper-middle income countries. In addition, Abadie (2021) suggests the co-movement of the outcome variable of interest across different units in the data is important to the success of finding the suitable synthetic control unit. The following countries are chosen to meet both criteria: Brazil, Canada, Ecuador, South Korea, Mexico, Malaysia, Saudia Arabia, Singapore and USA. For the analysis of sample restricted to the export flow to Annex B countries, Colombia, Jordan, Thailand, and Turkey are also included in the donor pool. Furthermore, the sample period is restricted to 1992–2012. The first reason lies at the fact that many countries did not report the trade until 1992. The inclusion of data before 1992 at this aggregate level (non-bilateral trade level) would cause misleading results. Second, the ridge SCM requires the panel data to be perfectly balanced, so restricting sample size from 1992 would result in more control units in the donor pool.

Plots of treated and synthetic control unit are shown in Fig. 7. In general, the treated unit and counterfactual unit match better in the analysis of export flow to Annex B countries. The ridge SCM fails to produce a synthetic control unit that fits Japan in the case of export flow to non-Annex B countries. The divergence of the treated unit and synthetic control unit suggests an effect of the KP on export flows to non-committed countries. Overall, the results indicate an increase in export of EGs in comparison with the "no-Kyoto" scenario.

The dynamic treatment estimation, presented in Table 5, suggests that the KP significantly leads to an increase in export of Germany to both Annex B and non-Annex B countries. This positive and significant effect is also observed in the export flow of Japan to Annex B countries. In summary, I find that there is indeed a positive effect of the KP on exports of EGs from Germany and Japan.

5.4 Mechanism

As introduced earlier, the three Kyoto mechanisms are designed to help committed countries flexibly meet their emission reduction targets. The project-based mechanisms, JI and CDM, are also expected to promote sustainable development through technology transfer and investment as well as encourage developing countries to make contribution to emission reduction efforts.[37] An *ex post* analysis of the registered CDM projects shows a significant increase in technology transfers and diffusion between Annex B countries and developing countries (Dechezleprêtre et al. 2008).[38] The technology transfer occurs when "the

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[36] More details about this method could be referred to Ben-Michael et al. (2021).

[37] See https://unfccc.int/process/the-kyoto-protocol/mechanisms

[38] It is important to note that the literature on evaluation of JI and CDM is controversial, as some other studies show skepticism on the role of these mechanisms. For instance, Cames et al. (2016) conclude that most of energy-related projects within CDM are not additional (i.e. the emission reductions would not have

technology used in the project is not available in the host country but must be imported" (Dechezleprêtre et al. 2008). Therefore, it is very likely that JI and CDM are the driving forces in the increase in exports of EGs.

According to the Kyoto mechanism design, CDM suggests the rise of exports of EGs from Annex B countries and imports of non-Annex B countries while JI could increase exports of EGs from some Annex B countries and imports of other Annex B countries. A comparison between the number of JI and CDM projects (327 versus 7,159 as of end of 2012) indicates that Annex B countries prefer conducting projects in developing countries.[39] This is reasonable as the cost of reducing emissions in developing countries is drastically smaller than that in other Annex B countries.

Statistics on CDM projects (registered until the end of 2012), presented in Table 6 show that the top five destinations for CDM projects are China, India, Brazil, Vietnam, and Mexico. Out of all registered projects, those conducted in China account for more than 50%. Meanwhile, nine out of ten committed countries that participate in these projects are among top ten exporters of the EGs. This suggests a correlation of CDM projects and exports of EGs.

To further establish the link, I examine the impact of KP on exports to China, which is the biggest host country in CDM and the largest non-Annex B importers of EGs. In particular, I restrict the analysis to the exports flow to China only. This restriction reduces the number of countries in the donor pool to 17.[40] Therefore, it is not possible to use GSCM due to the requirement of a minimum of 40 units in the donor pool. Therefore, I apply ASCM to evaluate whether there is any effect of the KP on exports of EGs to China. The analyses are conducted for the top five exporters: Germany, Japan, United Kingdom, France and Italy. Results are presented in Table 6. Plots of treated and synthetic units and ATT plots are demonstrated in Fig. 8. Of five countries, only Germany, Japan and Italy have well-matched pre-treatment fits. Besides, estimated effects are positive and generally significant during the post-treatment period.

One final point regarding the mechanism is the heterogeneity of commitments under the KP. As discussed in one robustness check in Sect. 5.2, some countries such as Eastern Europe do not have sufficient additional efforts in emission reduction. In addition, inclusion of these countries results in a bias in estimated treatment effect. Besides, in the proposed mechanism, these countries might serve as host of JI projects, which could lead to opportunities to increase their imports of EGs. On the other hand, major exporters of EGs (e.g. top five countries examined above) are those with stronger emission reduction targets. Thus, the project-based mechanism in the KP is the driving force of the increase in exports, yet conditional on the stringency level of commitments.

Footnote 38 (continued)

occurred in the absence of the mechanism). Besides, Wara (2007) and Kollmuss et al. (2015) revealed no or even negative effects of these mechanisms on emissions reductions.

[39] Statistics on JI and CDM projects are available at https://ji.unfccc.int/JI_Projects/DeterAndVerif/Verification/PDD/index.html and https://cdm.unfccc.int/Projects/projsearch.html

[40] The reduction in the number of available countries in the donor pool results from the fact that not all countries export to China. As there are only 17 countries left in the sample restricted to the export flow to China, I use all of them in the donor pool.

Table 6 Top ten host countries for CDM projects and top ten Annex B countries participating in CDM projects

Host country	No. registered projects	% of total registered projects	Annex B country	No. projects involved	% of total registered projects
China	3,682	51%	UK	2337	33%
India	1,369	19%	Switzerland	1584	22%
Brazil	300	4%	Netherlands	794	11%
Viet Nam	243	3%	Japan	585	8%
Mexico	180	3%	Sweden	545	8%
Malaysia	141	2%	Germany	404	6%
Indonesia	140	2%	France	277	4%
Thailand	129	2%	Spain	184	3%
Chile	94	1%	Italy	127	2%
Republic of Korea	86	1%	Austria	113	2%
Total	6,364	89%			

Some CDM Projects can have more than one Annex B countries investing and participating in. The total number of registered projects (6,364) reported in this table excludes those that were withdrawn or rejected

5.5 Does the KP Lead to Carbon Leakage?

As we have seen that the KP results in an increase in exports of EGs, then it is also likely that the protocol discourages the production of emission-intensive goods. As discussed in Section 2.3, a number of studies have found evidence on the decline of export of pollution-intensive products or carbon leakage induced by the KP (Aichele and Felbermayr 2013b, 2015). Therefore, whether the KP leads to a reduction in exports of emission-intensive goods or induces carbon leakage is an important angle to re-explore given the new empirical strategy in this study.

To examine this issue, this paper conducts additional analyses evaluating the impact of the KP on exports of pollution-intensive goods and carbon content of trade. Following Paraschiv (2016), this paper uses the harmonized EORA26 world input-output table (it is a part of the EORA World MRIO project developed by Lenzen et al. (2012, 2013)) to construct a dataset on industry-level, bilateral exports.[41] The reason for employing this dataset lies at the availability of sectoral carbon dioxide emissions. Having information on carbon dioxide emission is advantageous as it allows the construction of industry-specific carbon dioxide intensities (calculated as a ratio of annual CO_2 emissions to annual output) and the carbon content of exports (defined as a product of sectoral emission intensity and sectoral export flow). Hence, both export value and carbon content of exports are used as dependent variables in model (1).

The EORA26 dataset contains information on 14 service, 10 manufacturing and 2 primary sectors. To make the results comparable with Aichele and Felbermayr (2015), I follow Paraschiv (2016) and use two primary and 8 manufacturing sectors.[42] In addition, the

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[41] Data is available for download at https://worldmrio.com/eora26/

[42] The sectors in this analysis are agriculture, fishing, metal products, transport equipment, electrical and machinery, food & beverages, textiles & wearing apparel, petroleum, chemical and non-metallic mineral products, and wood & paper.
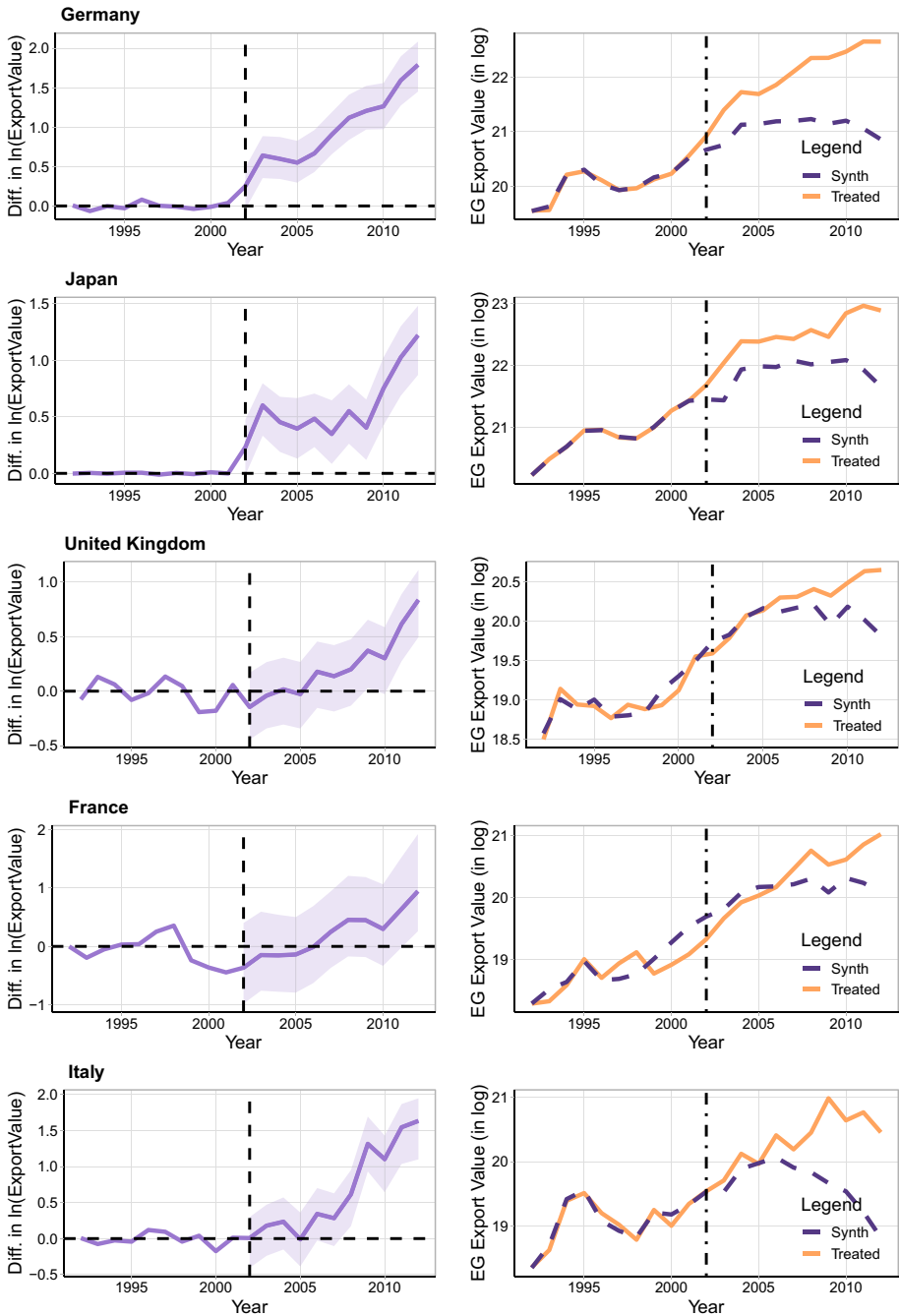
Fig. 8 Effect of the KP on exports to China using ridge SCM. *Notes.* This figure plots yearly treatment effect (on the left) and trend of export values (in log) of treated countries against its synthetic control (on the right) using ridge SCM. Shaded areas are 95% confidence interval based on jackknife+ approach in Barber et al. (2021)

Table 7 The effect of the KP on exports and carbon content of exports

	Exports	CO2 Exports		Exports	CO2 Exports
Agriculture			**Transport Equipment**		
ATT	0.112**	−0.075***	ATT	−0.016	0.021***
	(0.046)	(0.010)		(0.036)	(0.006)
MSPE	0.029	0.003	MSPE	0.063	0.017
Unobserved factors	3	3	Unobserved factors	3	1
Fishing			**Metal Products**		
ATT	0.029	−0.006*	ATT	−0.173***	−0.041***
	(0.036)	(0.003)		(0.031)	(0.004)
MSPE	0.026	0.006	MSPE	0.019	0.004
Unobserved factors	3	0	Unobserved factors	3	5
Electrical Machinery			**Petroleum, Chemical and Non-Metallic Products**		
ATT	−0.271***	−0.028**	ATT	−0.143***	−0.066***
	(0.042)	(0.012)		(0.034)	(0.013)
MSPE	0.015	0.009	MSPE	0.017	0.029
Unobserved factors	4	5	Unobserved factors	3	4
Food and Beverages			**Textiles and Wearing Apparel**		
ATT	−0.122***	−0.029	ATT	−0.043	−0.365***
	(0.045)	(0.023)		(0.051)	(0.053)
MSPE	0.026	0.029	MSPE	0.023	0.019
Unobserved factors	3	5	Unobserved factors	3	5
Wood and Paper			**Other Manufacturing**		
ATT	−0.146***	−0.003	ATT	0.006	−0.033***
	(0.039)	(0.007)		(0.045)	(0.013)
MSPE	0.022	0.003	MSPE	0.029	0.012
Unobserved factors	3	4	Unobserved factors	4	3
All Manufacturing Sectors					
ATT	−0.075**	−0.083***			
	(0.038)	(0.017)			
MSPE	0.018	0.026			
Unobserved factors	3	4			

Notes. The period of analysis is 1990–2012. Covariates are included in the analysis, but are not shown in the table. Standard errors, in parentheses, are based on parametric bootstraps of 1000 times. ***, **, * Significance at 1%, 5%, and 10%

data cover 189 exporters and 190 importers, but I restrict the sample size to be same as the data used in the main analysis for the purpose of comparison.[43] The EORA26 data are available over the period 1990–2015, but the analysis is again restricted to the period 1990 to 2012 to ensure consistency with the main result.

Summary statistics on sectoral export value and carbon content of exports are presented in Table 11. In terms of carbon dioxide content of exports, most manufacturing sectors have value greater than one. Industry of petroleum, chemical, and non-metallic mineral

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[43] In addition, running the full sample of 821,583 observations (189 exporters x 189 importers x 23 years) requires extremely high-power computers that my current laptop could not handle.
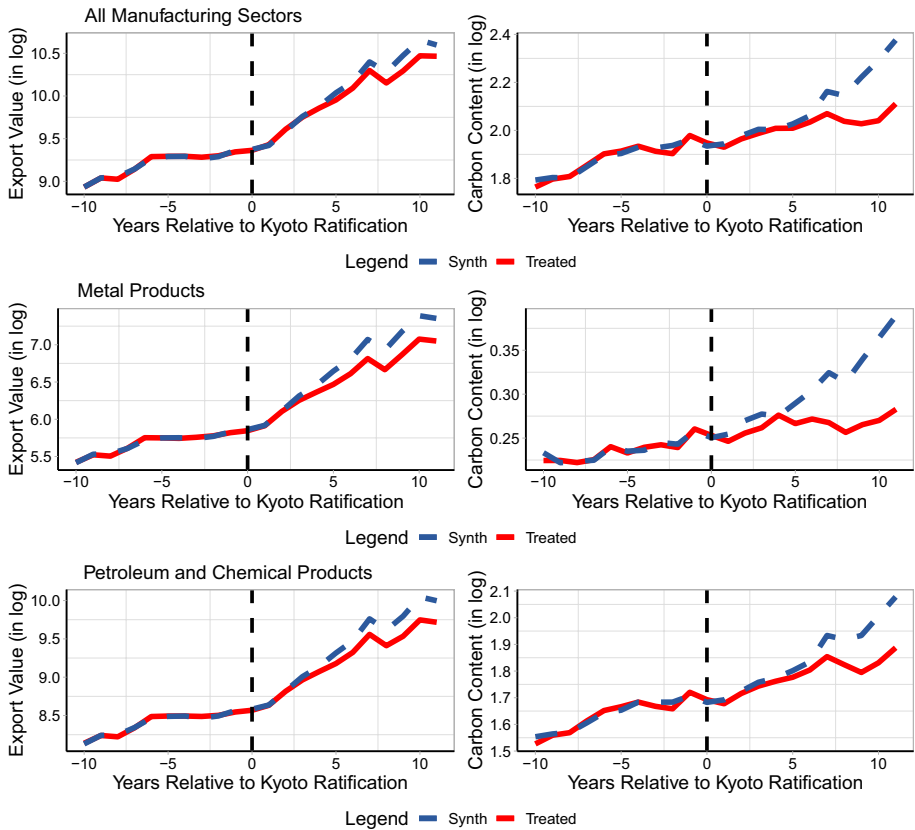
Fig. 9 Effect of the KP on exports of pollution-intensive goods and carbon content

products and industry of textiles and wearing apparel are the top two sectors that embody the largest content of carbon in their exports. These two sectors are among the top "dirtiest" ones as classified by Shapiro (2020). According to Shapiro (2020), of all 10 industries, petroleum, chemical, and non-metallic mineral products has the highest carbon dioxide rate (in range of 0.93–1.12 tons/$), followed by metal products and textile and wearing apparel.[44] Besides, the treated group (i.e. pairs with Annex B countries as exporters) have larger export value compared to the un-treated group. At the same time, country pairs with Kyoto commitments tend to have lower emission intensity and lower carbon content of export than those without Kyoto commitments in most sectors. This observation implies that it is possible that the KP would result in carbon leakage. Nevertheless, the following analyses would reveal the causal evidence to confirm this hypothesis.

As the information on carbon content of exports is available for each industry, I perform both aggregate and sector-by-sector analyses.[45] The results are reported in Table 7. Figure 9

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[44] CO_2 rates are measured in metric tons of CO_2 per thousand dollars of output. The higher the rate is, the dirtier the industry is. Information on the CO_2 rate for each industry is available from the replication files of Shapiro (2020).

[45] In the aggregate analysis, emission intensity is calculated by taking the ratio of carbon emission in all industries over output values in all industries.

presents the plot of treated and counterfactual averages for all industries and two sectors: metal products and petroleum, chemical, and non-metallic mineral products. The plots on the left side use export value as the dependent variable while the ones on the right side show carbon content of export. As it can be seen, the treated and the synthetic control averages have very similar trend in the pre-treatment period, suggesting success of the method in synthesizing the counterfactuals of the treated pairs. The graphs for the remaining sectors are in Figs. 12 and 13. Generally, the method also works well in finding the synthetic controls regardless of sectors or dependent variables used (except using carbon content of exports in industry of fishing).

There is heterogeneity in the results across industries, but overall there is a decline in at least export values or the carbon content of exports, even in non-emission-intensive industries. The top three emission-intensive industries according to Shapiro (2020) (i.e. metal products, petroleum, chemical and non-metallic mineral products, and textiles & wearing apparel) experience the biggest reductions in carbon content of exports in comparison with the "no-Kyoto" scenario. The carbon content of exports in the remaining sectors also significantly decreases. The only exception is industry of transport equipment, which sees a small increase in CO2 exports. The similar results are also observed in export value, but a few sectors such as agriculture, fishing, and other manufacturing have a small (and mostly insignificant) increase in value of exports. In summary, there is evidence for carbon leakage in manufacturing sectors after ratification of the KP.

6 Conclusion

With the increasing intensity of global warming and climate change, sustainable economic growth has become the main focus of many policymakers. Hence, the concept of IEAs and particularly the KP still seems to be a promising solution. However, whether it is worth implementing again is a controversial topic. While many studies present pessimistic views about the effect of the KP on carbon leakage and competitiveness loss, this paper is the first to provide evidence of its pro-green trade effect. Using the GSCM, this study demonstrates that, following the enforcement of the protocol, countries with commitment increased their export of EGs by 29 to 30%. The paper also investigates two case studies, Germany and Japan, and find robust the positive effect of the KP on their exports. A possible mechanism for this finding lies at the CDM, one of flexible mechanisms under the KP. The implementation of carbon emission reduction projects induces technology transfer and diffusion.

The results presented in this paper indicate the KP has been successful in stimulating sustainable development through technology transfer. Together with the findings about the effectiveness of the KP, these results indicate that it is possible to be optimistic about the effort that the community has invested in the battle against carbon emissions. However, these successes are possible thanks to the stringency of commitments under the KP. Hence, the participation of more countries, additional commitments, and stronger commitments from countries should be considered in future efforts in fighting climate change.

A - Additional Figures
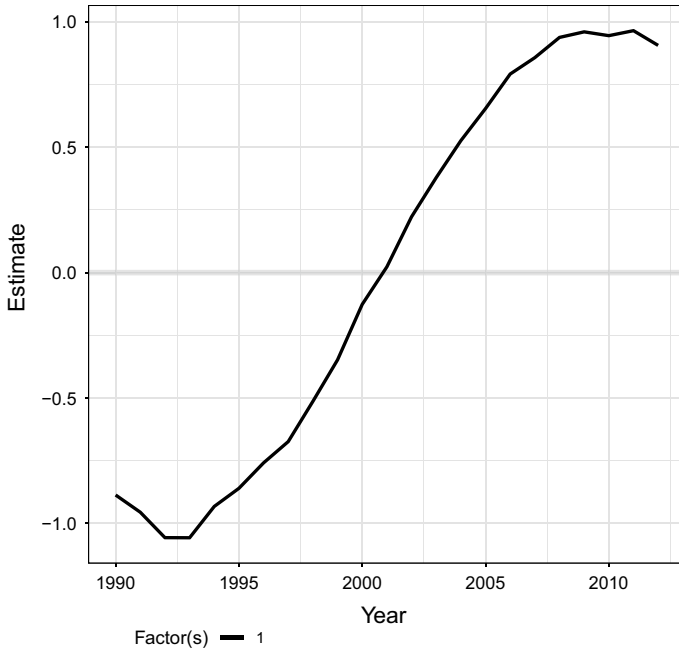
See Figs. 10, 11, 12 and 13.

Fig. 10 Factor loading

(a) Exclusion of the US as an exporter
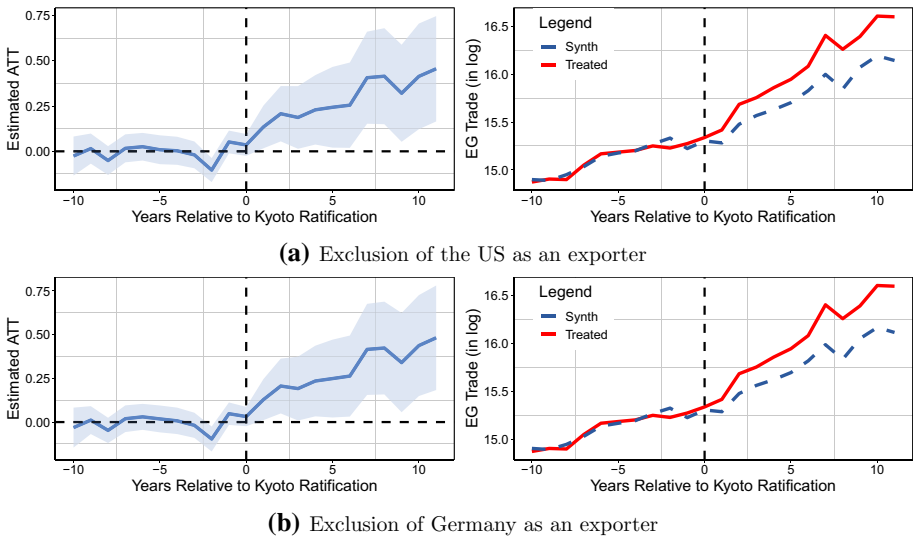

(b) Exclusion of Germany as an exporter

Fig. 11 Robustness check: Exclusion of big exporters. *Notes.* USA as an exporter is dropped from the analysis sample. Treatment period is the ratification year
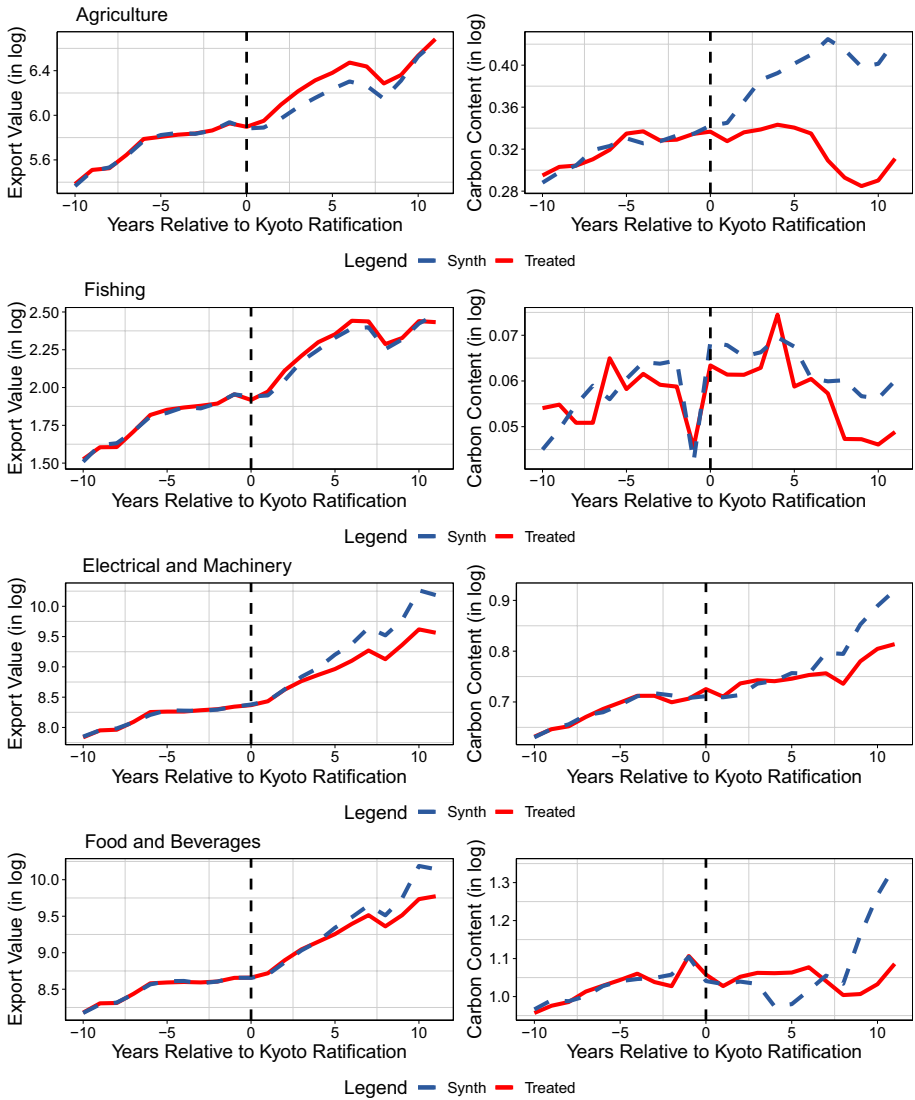
Fig. 12 Treated and counterfactual averages of export value (left) and carbon content of export (right) by sector
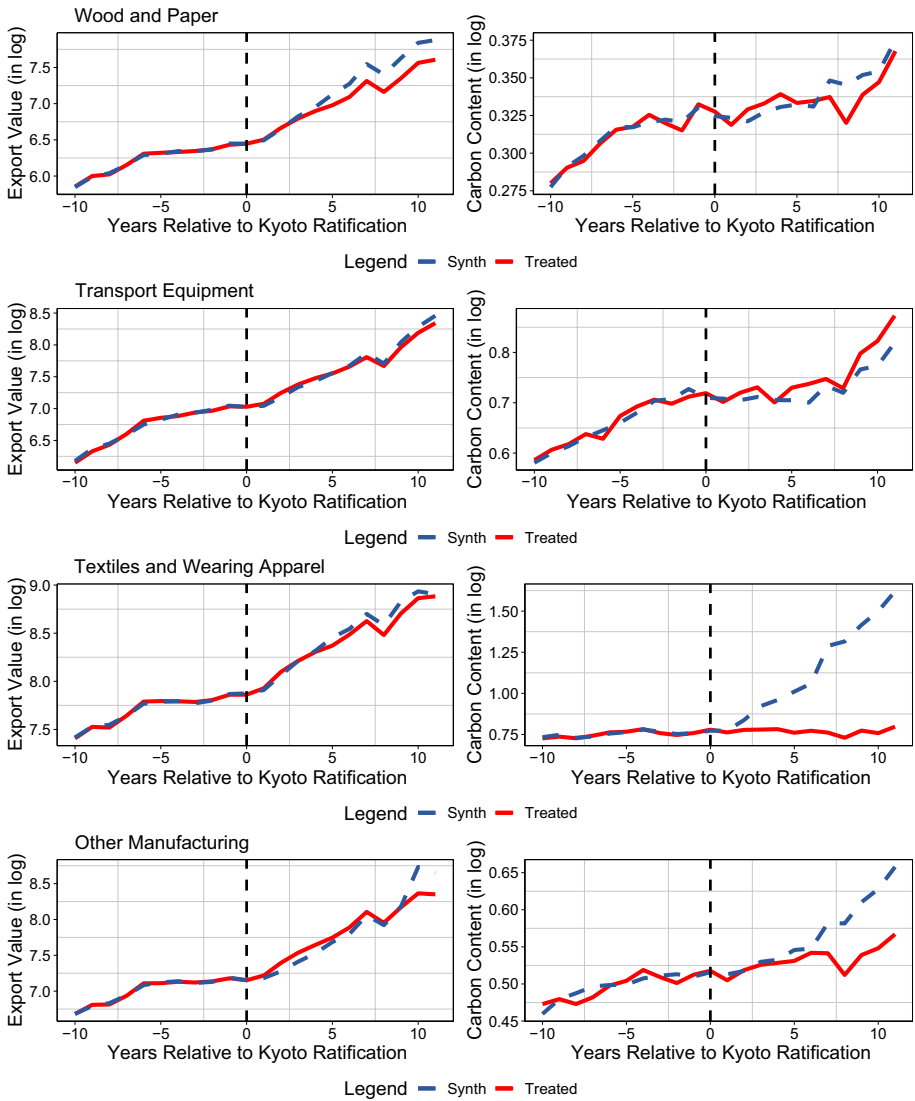
Fig. 13 Treated and counterfactual averages of export value (left) and carbon content of export (right) by sector (continued)

B - Additional Tables

See Tables 8, 9, 10, 11.

Table 8 Annex B countries in the analysis sample and ratification year

Australia - 2007	Austria - 2002	Belgium - 2002	Bulgaria - 2002
Czech Republic - 2001	Denmark - 2002	Finland - 2002	France - 2002
Germany - 2002	Greece - 2002	Ireland - 2002	Italy - 2002
Japan - 2002	Netherlands - 2002	New Zealand - 2002	Norway - 2002
Poland - 2002	Portugal - 2002	Romania - 2001	Russia - 2004
Spain - 2002	Sweden - 2002	Switzerland - 2003	Ukraine - 2002
United Kingdom - 2002			

(1) Source: https://treaties.un.org/Pages/ViewDetails.aspx?src=TREATY&mtdsg_no=XXVII-7-a&chapter=27&clang=_en. (2) Canada ratified in 2004 but withdrew from the protocol in 2012, so it is considered as "untreated"

Table 9 Definition of variables

Variable	Definition	Data source
$ExportValue_{pt}$	Value of bilateral export of the exporter– importer pair p in year t	UN Comtrade (2018)
$Kyoto_{pt}$	A dummy on whether the exporter of the exporter– importer pair p ratified the KP in year t	
GDP_{it}	GDP of exporter i in year t	World Bank
GDP_{jt}	GDP of importer i in year t	World Bank
$GDPC_{it}$	GDP per capita of exporter i in year t	World Bank
$GDPC_{jt}$	GDP per capita of importer j in year t	World Bank
$ENERGY_{pt}$	Energy intensity of the exporter– importer pair p, defined as the difference between exporter i and importer j in year t	World Bank Indicator (2019)
FTA_{pt}	A dummy on whether the exporter– importer pair p is member of a free-trade agreement in year t	De Sousa's database
$Currency_{pt}$	A dummy on whether the exporter– importer pair p is member of a common currency area in year t	De Sousa's database
EU_{pt}	A dummy on whether the exporter– importer pair p is member of European Union (EU) in year t	CEPII database
WTO_{pt}	A dummy on whether the exporter– importer pair p is member of World Trade Organization (WTO) in year t	CEPII database

Energy intensity data is available at https://data.worldbank.org/indicator/EG.EGY.PRIM.PP.KD. The CEPII dataset can be found at http://www.cepii.fr/CEPII/en/bdd_modele/presentation.asp?id=8. De Sousa's gravity data on common currency and FTA can be found at http://jdesousa.univ.free.fr/data.htm

Table 10 List of countries in the analysis

Albania	Algeria	Angola*	Antigua and Barbuda*	Argentina
Armenia*	Australia	Austria	Azerbaijan	Bahamas*
Bahrain*	Bangladesh	Barbados*	Belarus*	Belgium
Belize	Bhutan*	Bolivia	Brazil	Brunei Darussalam*
Bulgaria	Burkina Faso	Burundi**	Cabo Verde*	Cameroon
Canada	Central African Republic**	Chile	China	China, Hong Kong
China, Macao	Colombia	Congo*	Costa Rica	Cuba*
Cyprus	Czechia	Côte d'Ivoire	Democratic Republic of the Congo*	Denmark
Dominica*	Dominican Republic*	Ecuador	Egypt	El Salvador
Equatorial Guinea*	Ethiopia	Fiji*	Finland	France
Gabon*	Gambia**	Georgia	Germany	Ghana*
Greece	Grenada*	Guatemala	Guinea*	Guyana
Honduras	India	Indonesia	Iran*	Ireland
Israel	Italy	Jamaica	Japan	Jordan
Kazakhstan*	Kenya*	Kyrgyzstan*	Lebanon*	Madagascar
Malawi	Malaysia	Mali*	Malta*	Mauritania*
Mauritius	Mexico	Mongolia	Morocco	Mozambique*
Myanmar*	Nepal*	Netherlands	New Zealand	Nicaragua
Niger	Nigeria*	Norway	Oman	Pakistan*
Panama	Paraguay	Peru	Philippines	Poland
Portugal	Republic of Korea	Romania	Russian Federation	Saint Kitts and Nevis
Saint Lucia	Saint Vincent and the Grenadines	Saudi Arabia	Senegal	Seychelles
Sierra Leone*	Singapore	South Africa	Spain	Sri Lanka
Sudan*	Suriname*	Sweden	Switzerland	Tajikistan*
Thailand	The former Yugoslav Republic of Macedonia	Trinidad and Tobago	Tunisia	Turkey
Turkmenistan*	Uganda	Ukraine	United Arab Emirates*	United Kingdom
United Republic of Tanzania	United States of America	Uruguay	Uzbekistan*	Vanuatu*
Viet Nam*	Yemen*	Zambia	Zimbabwe*	

*Denotes country appearing as exporter only in the sample. ** denotes country appearing as importer only in the sample

Table 11 Summary Statistics of EORA26 dataset

Variables	All		Pairs with Annex B Countries as exporter		Pairs with non-Annex B Countries as exporter	
	Mean	SD	Mean	SD	Mean	SD
Agriculture						
Export Value	14.37	82.58	22.99	94.88	12.95	80.29
Carbon Content	1.236	7.314	0.950	3.454	1.283	7.766
Fishing						
Export Value	1.660	13.29	3.076	17.24	1.428	12.50
Carbon Content	0.142	1.255	0.0998	0.698	0.149	1.325
Electrical and Machinery						
Export Value	52.49	456.5	83.60	310.1	47.37	476.1
Carbon Content	6.523	96.37	3.448	17.18	7.029	103.7
Food and Beverages						
Export Value	56.26	274.2	133.9	405.8	43.50	243.5
Carbon Content	6.847	38.86	6.806	20.45	6.853	41.10
Wood and Paper						
Export Value	8.073	51.21	19.61	65.88	6.178	48.11
Carbon Content	0.824	8.585	0.822	2.577	0.825	9.204
Transport Equipment						
Export Value	58.91	717.9	161.1	1,085	42.11	636.0
Carbon Content	4.865	61.46	8.263	67.15	4.306	60.46
Metal Products						
Export Value	4.135	29.64	8.131	23.30	3.478	30.50
Carbon Content	0.792	9.013	0.554	1.869	0.831	9.696
Petroleum, Chemical, and Non-Metallic Mineral Products						
Export Value	49.05	284.7	135.3	508.3	34.88	224.6
Carbon Content	22.99	155.3	32.10	145.9	21.49	156.7
Textiles and Wearing Apparel						
Export Value	79.32	686.2	103.4	504.7	75.36	711.6
Carbon Content	15.03	184.1	5.105	21.65	16.66	198.4
Other Manufacturing						
Export Value	29.44	300.8	47.11	182.8	26.54	315.9
Carbon Content	5.031	82.51	2.125	8.491	5.508	88.95
Total						
Export Value	353.7	2,226	718.2	2,426	293.8	2,186
Carbon Content	73.38	639.7	62.18	202.2	75.22	685.4

Export value is in million USD. Carbon content of exports is in Gg (kt) of CO_2

Declarations

Statement of exclusive submission "This paper has not been submitted elsewhere in identical or similar form, nor will it be during the first three months after its submission to the Publisher"

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