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Kyoto and the Carbon Footprint of Nations

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Abstract

A country's carbon footprint refers to the CO_2 emissions caused by domestic absorption activities. Trade in goods drives a wedge between the footprint and local emissions. We provide a panel database on carbon footprints and carbon net trade. Using a differences-in-differences IV estimation strategy, we evaluate the Kyoto Protocol's effects on carbon footprints and emissions. Instrumenting countries' Kyoto commitment by their participation in the International Criminal Court, we show that Kyoto reduced domestic emissions in committed countries by 7%, has not lowered footprints, but increased the share of imported over domestic emissions by 17 percentage points. This indicates carbon leakage.

JEL Code: F18, F53, Q54, Q58.
Keywords: Carbon content of trade, carbon footprint, carbon leakage, evaluation model, instrumental variables.

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1 Introduction

A country's *carbon footprint* accounts for all carbon emissions that the country's residents cause by consuming or investing a specific vector of goods. Whether these goods are produced domestically or imported does not matter.[1] However, the carbon inventories drawn up by the UN's Framework Convention on Climate Change (UNFCCC) measure *domestic emissions*, i.e., the amount of carbon embodied in the vector of goods produced on a nation's territory. With international trade in goods, a country's carbon footprint and its domestic CO_2 emissions need not coincide, the difference being the *carbon content of net trade.*

This paper provides the first econometric *ex post* analysis of the Kyoto Protocol, thereby complementing computable general equilibrium (CGE) analyses such as the one by Elliott et al. (2010). For this purpose, it assembles a new *panel* database on the carbon footprint of nations. It uses an instrumental variables (IV) strategy to study the effects of commitments made by some countries under the Kyoto Protocol on countries' CO_2 emissions and carbon footprints. The key finding is that, on average, Kyoto has caused some domestic emission savings. But it has also caused increased net imports of carbon so that the carbon footprint of countries has not changed. *Carbon leakage* due to the Protocol's incomplete coverage has therefore neutralized emission savings.

The international policy community cares about anthropogenic CO_2 emissions because they are believed to trigger global warming, which can have large negative consequences for global welfare (Stern, 2007). The Kyoto Protocol has been the first multilateral attempt to cap carbon emissions. Many observers think that the design of the Protocol is fundamentally flawed because it exempts emerging and developing countries,[2] and it lacks an enforcement mechanism. Whether it has actually affected countries' emissions, their carbon footprints or the carbon content of net trade is an unsettled empirical question. For any successful future international agreement on climate policies, more needs to be known about the empirical relevance of the leakage phenomenon.

Several difficulties affect the empirical analysis. First, selection of countries into the Kyoto Protocol may be non-random so that estimating treatment effects requires instrumental variables. Second, there is no harmonized synthetic cross-country measure of climate policy. Following the related literature, we work with Kyoto commitment dummies. However, these dummies are noisy indicators of true climate policy.

[1] This is the flow version of the carbon footprint. The stock version refers to *accumulated* emissions embodied in goods absorbed over a country's existence.

[2] The USA has not ratified the treaty, presumably because it "leaves out developing countries such as China and India" (Feenstra and Taylor, 2008, p. 426).

Containing the ensuing attenuation bias again requires good instruments. Third, for statistical inference we need to minimize errors in the measurement of countries' carbon footprints. We use high quality input-output (I-O) tables and sectoral emission coefficients from official sources to calculate footprints. These data are available only for 40 countries and the period 1995-2007. Covering more than 80% of the world's emissions, our data allows using differences-in-differences techniques to measure the impact of Kyoto commitments on domestic CO_2 emissions, carbon footprints and net imports.

We report the following findings. First, carbon emissions embodied in international trade flows are quantitatively important: in 1995, about 9% of emissions were traded; in 2007 this measure is up to 15%. The increase started in 2002, the first year of China's WTO membership and the year in which most countries ratified their Kyoto commitments. Second, there is substantial variation across countries in the levels and growth rates over time of domestic CO_2 emissions and carbon footprints. Third, a naive inspection of the data suggests that growth rates of carbon footprints do not correlate with Kyoto commitment status, but growth rates of domestic CO_2 emissions do. Fourth, we show that countries' ratification of the Rome Statute governing the International Criminal Court (ICC) predicts Kyoto commitment. Our identifying assumption is that a country's stance on the ICC has no effect on domestic emissions or footprints so that the ICC membership dummy can be excluded from our second-stage instrumental variables regressions. The same holds true for trading partners' ICC status. Fifth, we use these instruments in a differences-in-differences setup. We find that Kyoto commitments have reduced domestic CO_2 emissions on average by about 7% (relative to the unobserved counterfactual), but the carbon footprint has not decreased. As a consequence, the ratio of CO_2 imports over domestic CO_2 emissions (the carbon imports ratio) has increased on average by about 17 percentage points.

Related Literature. A number of *descriptive* studies present estimates of the carbon footprint of nations. Hertwich and Peters (2009) do so for 87 countries and 2001 data;[3] Davis and Caldeira (2010) update the analysis to 113 countries and 2004 data. These papers make an impressive effort toward a comprehensive view on the carbon footprint of nations by including other major greenhouse gases such as CH_4, N_2O or F-gases, by accounting for agricultural production, land-use change, international transportation, and the non-market sector (heating). Only recently a panel data set for 113 regions has been proposed by Peters et al. (2011). The authors provide detailed estimates for the years 1997, 2001 and 2004 and base their analysis on raw data from the Global Trade Analysis Project (GTAP).[4] In our

[3]Their data are very nicely presented on a website `www.carbonfootprintofnations.com/`.

[4]GTAP I-O data may suffer from measurement problems as they are not based on a harmonized data collection and processing approach. Also, yearly sectoral emission and output data is available for only half of those countries.

econometric exercise, to minimize measurement error in the dependent variable, we must restrict the analysis to those 40 countries for which the OECD provides high quality I-O tables and for which there is official data to generate *yearly sectoral* emission coefficients.

Our study relates to a large tradition in empirical economics to analyze the effects of international or domestic institutional arrangements on economic outcomes. In virtually all applications, reverse causation is an issue as the choice of institutions (or policies) and the membership in international organizations is not exogenous. Moreover, membership is measured by simple dummy variables.[5]

There is a rich theoretical and quantitative literature on the effectiveness of climate policies in the presence of international trade; see Copeland and Taylor (2005) for an important early contribution and de Melo and Mathys (2010) for a survey. An important CGE study by Babiker (2005) uses a model with increasing returns to scale and an Armington demand system and finds carbon leakage in excess of 100% in one scenario. Recent work focuses on border tax adjustments as remedies to the carbon leakage problem. Mattoo et al. (2009) highlight how border tax adjustments could harm developing economies. Elliott et al. (2010) find substantial carbon leakage ranging from 15% at low tax rates to over 25% for the highest tax rate. Our approach complements the ex ante perspective of CGE models by carrying out an ex post evaluation of the Kyoto Protocol's effect on the carbon footprint, emissions, and trade.

The structure of the paper is as follows. In section 2 we describe how we construct our panel database on nations' carbon footprints. Section 3 discusses the selection of countries into commitments under the Kyoto Protocol and presents our instrumental variables strategy. Section 4 contains our main results and an array of robustness checks.

2 Measuring the carbon footprint of nations

2.1 Method and data

In the presence of international trade, domestic emissions need not coincide with the CO_2 embodied in domestic consumption and investment, i.e., the country's *carbon footprint*. To calculate the carbon footprint, one has to measure the *carbon content of trade*, i.e., the CO_2 emissions embodied in a country's net trade vector. Country i's carbon footprint at time t, $F_{i,t}$, is defined as

$$F_{i,t} \equiv E_{i,t} + EET_{i,t}, \tag{1}$$

[5] As examples, see the literature on the effects of IMF (Dreher and Walter, 2010) or WTO membership (Rose, 2004a,b).

where $E_{i,t}$ are country $i's$ domestic CO_2 emissions at time t and $EET_{i,t}$ are the CO_2 emissions embodied in net imports.

Accounting method. To obtain a precise estimate of $EET_{i,t}$, it is crucial to account for the increasing importance of trade in intermediates and re-exports. Therefore, one has to track each product and its components along the global production chain to the respective country of origin.[6] As an example, let country A's sector h use an intermediate input from country B. Country B might assemble this intermediate from intermediates produced locally or in a country C, D or even A, and so forth. All those upstream emissions (occurring locally or abroad) must be associated to the final consumption of good h. The *multi-region input-output (MRIO) method* provides the accounting rule, see e.g. Trefler and Chun Zhu (2010). A MRIO table collects all bilateral inter-industry demand linkages into a world I-O table $\mathbf{B}$:[7]

$$\mathbf{B} \equiv \begin{pmatrix} \mathbf{B}_{11} & \cdots & \mathbf{B}_{1N} \\ \vdots & \ddots & \vdots \\ \mathbf{B}_{N1} & \cdots & \mathbf{B}_{NN} \end{pmatrix}, \tag{2}$$

where $\mathbf{B}_{ij}$ is the *bilateral I-O table* of intermediates produced in country i and used in country j and N is the total number of countries. Bilateral I-O tables $\mathbf{B}_{ij}$ are derived from reported multilateral tables $\bar{\mathbf{B}}_j$ under the assumption that country i's share of intermediates h in country j's sector g is proportional to its import share in this sector.[8]

Let $\mathbf{e}_i$ be country i's sectoral CO_2 emission intensities vector, $\mathbf{X}_i$ its vector of sectoral exports and $\mathbf{M}_{ij}$ its vector of sectoral imports from country j. Then the world emission vector $\mathbf{e}$ and the trade matrix $\mathbf{T}$ are defined as

$$\mathbf{e} \equiv \begin{pmatrix} \mathbf{e}_1 & \cdots \mathbf{e}_N \end{pmatrix}, \ \mathbf{T} \equiv \begin{pmatrix} \mathbf{X}_1 & \cdots & -\mathbf{M}_{N1} \\ \vdots & \ddots & \vdots \\ -\mathbf{M}_{1N} & \cdots & \mathbf{X}_N \end{pmatrix}. \tag{3}$$

Accordingly, the carbon content of trade is given by

$$EET_i = \mathbf{e}(\mathbf{I} - \mathbf{B})^{-1}\mathbf{T}, \tag{4}$$

[6] This is crucial since Metz et al., eds (2007) document wide cross-country heterogeneity in production structures and sectoral carbon intensities.

[7] To avoid notational clutter, we suppress time indices in the following.

[8] Country $j's$ use of sector g inputs from country $i's$ sector h is $B_{ij}(h,g) = \theta_{ji}(h)\bar{B}_j(h,g)$, where the import share is $\theta_{ji}(h) \equiv M_{ji}(h)/(Q_j(h) + \sum_k M_{jk}(h) - X_j(h))$ and $Q_j(h)$ is country j's output in sector h; see OECD (2002, p. 12).

where $(\mathbf{I} - \mathbf{B})^{-1}$ is the Leontief inverse of the I-O table, and $\mathbf{I}$ is the identity matrix. So, to empirically compute $EET_{i,t}$, one requires input-output tables, bilateral trade data, and sectoral CO_2 emission coefficients, ideally all for the year t.

The data. Harmonized I-O tables for our 40 sample countries are taken from the OECD Input-Output Tables 2009. They are observed around the years 1995, 2000, and 2005.[9] We aggregate the I-O data to 15 ISIC industries to match the available emissions data. We obtain bilateral goods trade data in f.o.b. values from the UN Comtrade database. We use a concordance table provided by Eurostat[10] to translate the data from the SITC commodity classification into ISIC. Information on the level of sectoral CO_2 emissions from fuel combustion come from the International Energy Agency (IEA).[11] In order to obtain emission coefficients, we divide sectoral emission levels by some measure of sectoral output. Output data is obtained from the OECD Structural Analysis Database, the UNIDO Industrial Statistics Database (INDSTAT4), the UN System of National Accounts,[12] and OECD I-O tables.[13] Our database comprises 40 countries over the period 1995 to 2007; countries are listed in Table I. To model the rest of the world (RoW), we argue that countries at a similar stage of economic development have similar production technologies. Therefore, we group countries into three classes according to their level of real GDP per capita, obtained from the Penn World Table 6.3. Each RoW country is assigned a weighted average of emission coefficients and I-O tables of sample countries in the same real GDP class.[14]

2.2 Descriptive evidence

Emissions and carbon footprint. Figure 1 tracks CO_2 emission levels in logs for the whole world and for our sample. The upper (gray, solid) curve relates to the entire world and measures CO_2 emissions as reported by the IEA. From 1995 to 2007 emissions have increased by about 33% (an increase of 7.2 gigatons of CO_2); about two thirds of this increase occurred after 2002, the first year of China's WTO membership and most countries' year of Kyoto ratification. The second curve (black, solid) reports

[9] We used the I-O tables from 1995 for the years 1995-97, those from 2000 for 1998-2002, and those from 2005 for 2003-07. Linearly interpolating between observed I-O tables yields very similar results.

[10] http://ec.europa.eu/eurostat/ramon.

[11] They include CO_2 produced during consumption of solid, liquid, and gas fuels and gas flaring as well as the manufacture of cement. Note that other sources of CO_2 emissions such as fugitive emissions, industrial processes or waste are disregarded. However, CO_2 emissions from fuel combustion make up roughly 80% of total CO_2 emissions.

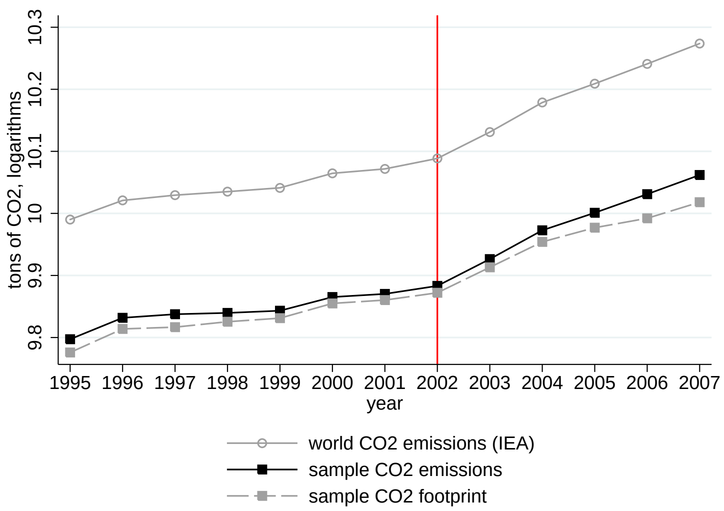
[12] http://data.un.org/Data.aspx?d=SNA&f=group_code%3a203.

[13] For some countries and years sectoral output data are missing. We impute missing output data by applying growth rates of output or where those were not available growth rates of real GDP of the respective country and year.

[14] Alternatively, we apply US emission coefficients and I-O tables to RoW. The obtained carbon footprint series are virtually the same.

emissions for our sample of 40 countries. Over the whole period of 13 years, our sample covers a fairly constant share of about 81.5% of world emissions. The curve closely tracks the behavior of the world total. Finally, the last curve (gray, dashed) shows the carbon footprint of our sample. This measure closely tracks our emission data, but not perfectly. The reason is that we do not force our sample world to be closed; rather, there is trade with the rest of the world. Over the sample period, our sample countries have consistently run a trade surplus in terms of carbon (i.e., carbon emissions in the group exceed the carbon footprint).

Figure 1: CO_2 emissions in the world and in the sample

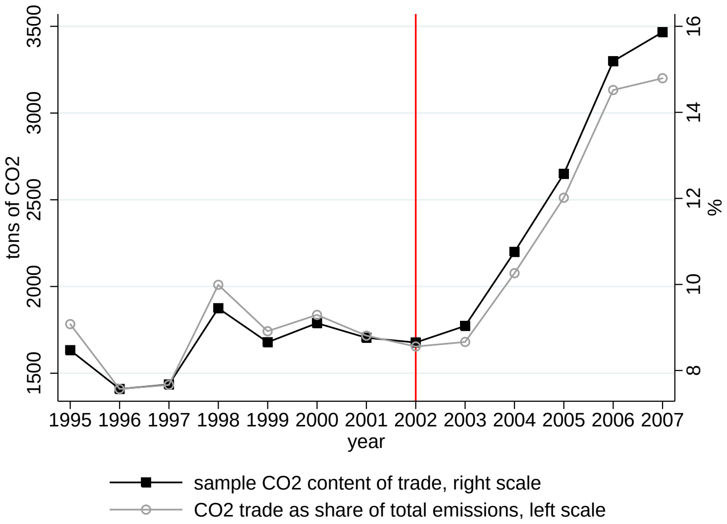


Source: Inventoried emissions data from the IEA; Carbon footprint: own calculations. World corresponds to 187 countries; sample to 40 countries.

Trade in goods and embodied emissions. Figure 2 plots the evolution of CO_2 emissions embodied in international trade (black line). Trade in carbon has increased by about 112% between 1995 and 2007, the largest share of the absolute increase (92%) happening after 2002. The gray line in Figure 2 tracks the share of carbon trade in total emissions. The share remains fairly constant around 9% from 1995 to 2002 but increases drastically from 2003 onwards to reach 15% in 2007. This is partly explained by a quite substantial increase in the carbon intensity of trade from 2003 onwards (not shown).

Country level comparisons. Table I shows detailed information about the countries included in our sample. With five exceptions (Australia, Czech Republic, Romania, Russia and Switzerland), ratification of the Kyoto Protocol has taken place in the year of 2002. In 1995, emissions per capita (in tons of CO_2) vary dramatically across countries. At the lower end, emissions per capita in India or Indonesia are 0.85 and 0.97 tons, while they are 19.26, 15.87, and 15.67 tons per capita at the higher end in the

Figure 2: CO_2 content of trade and share of CO_2 emissions traded



Source: CO_2 content of trade: own calculations. Sample (40 countries).

US, Australia, and Canada. Average yearly growth rates of per capita emission levels range from 5.16% in China to -1.97% in Sweden.[15] Regressing those growth rates on the logarithm of initial emission levels yields a coefficient of -1.26 (robust t-value -4.67), so that there is a substantial amount of (absolute) convergence.

Turning to carbon footprints, countries with high per capita emissions also have high per capita footprints; the coefficient of correlation is 0.92. There is also evidence for convergence, but the estimated coefficient is smaller (-0.78, t-value -5.06). However, the coefficient of correlation between the growth rates of per capita emissions and footprints is 0.28 and only marginally significant. Finally, the last two columns in Table I show net CO_2 imports in percent of domestic emissions of the years 1995 and 2007. Somewhat less than two thirds of countries have positive net imports. Net carbon imports can be very substantial: e.g., in 2007, Switzerland imports goods that embody almost 156% of domestic CO_2 emissions. Imports in Sweden, Netherlands, Denmark, Norway, Ireland and France also exceed 30% of domestic emissions. The share of carbon emissions exported is highest in China (30%), South Africa (24%), the Czech Republic (24%) and Australia (16%).

[15] Since our starting year is 1995, industrial restructuring in formerly communist economies has mostly come to an end.

3 Empirical strategy

3.1 Differences-in-differences estimation

We are interested in estimating the effect that Kyoto commitment has on countries' carbon dioxide emissions, carbon footprints, and carbon trade. Our working hypothesis is that the year of ratification of the Kyoto Protocol in national parliaments designates the point in time from which on Kyoto may have had an impact on policies and, thus, on outcomes. Anecdotal evidence suggests that countries have engaged in a flurry of policy initiatives after ratification.[16]

In order to estimate the average treatment effect of a Kyoto commitment, we use a differences-in-differences approach. To avoid reporting spurious results, we follow Bertrand et al. (2004) and work with long averages rather than with yearly data. For this purpose, we define different treatment periods and corresponding pre- and post-treatment periods. Our preferred specification defines the treatment period as the years 2001-03, when all countries (except Russia and Australia) have ratified the Protocol. The pre- and post-treatment period are symmetric around the treatment period and defined as the four-year intervals 1997-2000 and 2004-07.[17] Hence, we base our analysis on 80 pre- and post-treatment averages. This strategy deals with country-specific business cycles. First-differencing eliminates any country-specific time-invariant determinants of the relevant outcome variables (e.g., climatic conditions, endowments with different types of energy resources, geographic location, preferences of the representative consumers, etc.) thereby reducing omitted variables bias. Hence, the specification takes the form

$$\begin{aligned} \Delta Outcome_{i,t} &= \delta + \beta \Delta Kyoto_{i,t} + \xi \Delta \mathbf{X}^{'}_{i,t} + \upsilon_{i,t}, \qquad (5) \\ Outcome_{i,t} &\in \left\{ \ln E_{i,t},\, \ln F_{i,t},\, \frac{EET_{i,t}}{E_{i,t}} \right\}, \end{aligned}$$

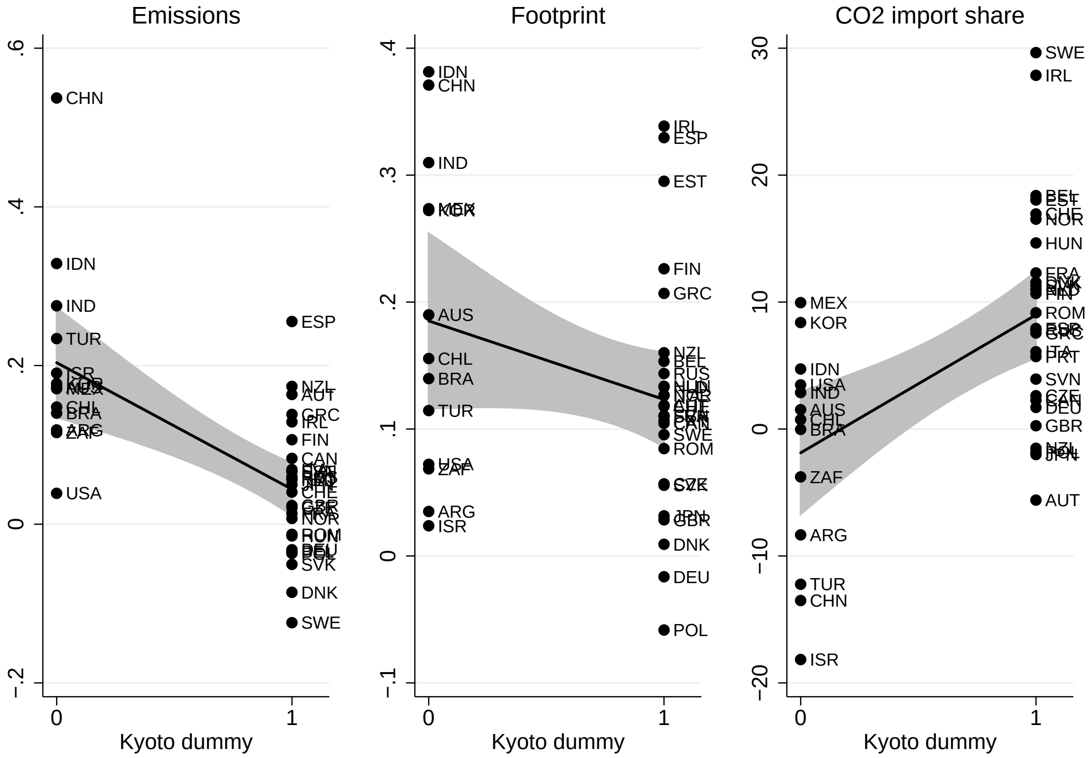
where Δ denotes the first difference operator, and $t \in \{pre, post\}\,(T = 2)$. δ is a constant accounting for a common time trend that would affect the treatment and the control groups alike. $E_{i,t}, F_{i,t}, EET_{i,t}$ are defined in (1). $\mathbf{X}_{i,t}$ is a vector of controls and includes amongst others the log of population, the log of GDP and an EU dummy. The controls are motivated in more detail when presenting the results. $Kyoto_{it}$ is a dummy taking value 1 if country i has Kyoto commitments in period t. Due to our two-period setup, $\Delta Kyoto_{i,t} = Kyoto_{i,t}$. We correct the variance-covariance matrix for heteroskedasticity. Before addressing the crucial question of instrumenting $Kyoto$, we set $\xi = \mathbf{0}$ in equation (5) and show scatter

[16] See data displayed on www.lowcarboneconomy.com/Low_Carbon_World/Data/View/12.

[17] Russia has ratified in 2004 and is counted as treated in our analysis; Australia has ratified in late 2007 and is put into the control group. We present robustness checks pertaining to these choices below.

plots and univariate regressions to obtain a first impression on the effect of Kyoto on outcome variables.

Figure 3: Kyoto commitment and changes in log carbon emissions, log footprint, and import share



Note: The graphs show scatter plots of differences between pre- and post-treatment period averages in log CO_2 emissions and footprints per capita and in the share of CO_2 imports over domestic emissions for committed and non-committed countries. The graphs also show fitted linear regression lines with 95% (heteroskedasticity-robust) confidence intervals.
Regression coefficients and robust standard errors (in parentheses): Emissions −0.16*** (0.00); footprint −0.06 (0.12); carbon import ratio 10.87*** (0.00).

Figure 3 plots the change between the pre- and post-treatment period average of log CO_2 emissions, log carbon footprints (both in per capita terms) and the carbon import share against the Kyoto commitment dummy. The left-most panel reveals that between the two periods domestic CO_2 emissions have, on average, grown by 20% in the subsample of non-committed countries compared to 4% in the subsample of committed countries. This difference, 16 percentage points, is statistically significant at the 1% level. When looking at the middle panel – footprints – the evidence is less clear-cut. On average, the growth rate of per-capita carbon footprints appears by 6 percentage points higher in the subsample of non-committed countries, but that difference is not statistically significant. Finally, the right-most panel compares the change in the CO_2 import share. That share has increased by 11 percentage points more in the sample of committed countries, the difference being statistically significant at the 1% level.

The evidence displayed in Figure 3 is suggestive. It points toward the possibility that Kyoto commitments have indeed reduced domestic CO_2 emissions, but not the carbon footprint. Kyoto would thus have led to delocation of carbon-intensive production and to an increase in carbon trade, but not to a reduction of committed countries' absorption as captured by the carbon footprints. While Figure 3 can deal with constant level differences across countries and common time trends, it cannot address the non-random selection of countries into the Kyoto Protocol. The reported effects may be spurious if countries with beneficial emission projections, for example, might be more willing to commit to an emission target under Kyoto. The next section models countries' selection into Kyoto and identifies variables that explain selection but not emissions.

3.2 Instrumental variable strategy

In this paper, we propose countries' membership at the *International Criminal Court* as an instrument for Kyoto commitment. The ICC, headquartered in The Hague, Netherlands, is a permanent tribunal to prosecute individuals for genocide, crimes against humanity, war crimes, and the crime of aggression. Like the UNFCCC, the ICC is a multilateral policy initiative under the umbrella of the United Nations Organization. The Rome Statute governing the ICC was finally signed in 1998 and ratified, until December 2010, by 114 countries. 34 countries, including the US, India, and China, have decided not to ratify the Statute. Groves (2009) likens the Kyoto Protocol to the Rome Statute and argues that both initiatives threaten US sovereignty.[18] Indeed, countries' preferences for multilateral international policy initiatives, proxied by their involvement in the ICC, turn out to correlate robustly to Kyoto commitment. The maintained assumption is that ICC involvement of a country is not caused by carbon emissions or the footprint and that it does not directly affect these outcome variables, neither.[19]

Our selection equation takes the following form

$$\Delta Kyoto_{i,t} = \alpha_0 + \alpha_1 \Delta ICC_{i,t} + \alpha_2 \Delta W.ICC_{i,t} + \alpha_3 \Delta \ln Pop_{i,t-1} + \zeta \Delta \mathbf{Z}'_{it} + \varepsilon_{it}, \quad (6)$$

where ICC_{it} is a dummy taking the value 1 if a country has ratified the Rome Statute. Data on ICC membership stems from the UN Treaty Series database. The variable $W.ICC_{i,t}$ captures ICC membership of other countries and is computed as $\sum_{j \neq i} \frac{Pop_{j,t}}{Dist_{ij}} ICC_{j,t}$, where $Dist_{ij}$ is geographical distance between countries i and j, and $Pop_{j,t}$ is population. $Pop_{j,t}/Dist_{ij}$ is a conventional spatial weight. It ensures that

[18] Similarly, Mike Huckabee (2007), former Governor of Arkansas, argues that the Kyoto Protocol "would have given foreign nations the power to impose standards on us." China's stance in the Copenhagen climate change negotiations was similar.

[19] Other multilateral treaties, such as those governing the WTO or international environmental questions cannot be easily excluded since they will affect emissions directly either through "green" preferences of voters and consumers, or through trade policy.

$W.ICC_{i,t}$ increases when other countries ratify the Rome Statute, and does so most when those countries are large and close by. Data on population and GDPs stem from the World Bank World Development Indicators and data on bilateral distance from the CEPII distance database. $\ln Pop_{i,t-1}$ refers to the log of population as of the period *before* the pre-treatment period. The ICC and lagged population variables are the instruments that we exclude from our second-stage regressions. The vector $\mathbf{Z}_{it}^{\prime}$ may coincide with the vector $\mathbf{X}_{it}^{\prime}$ of equation (5). It may contain other potential variables that may play a role for the selection of a country into the Kyoto Protocol such as WTO_{it} and EU_{it}; dummy variables that take value 1 if country i is a WTO or EU member at time t, respectively. The vector also includes $\ln MEA_{i,t}$ which counts the number of multilateral environmental agreements (MEAs) other than the Kyoto Protocol that country i has ratified up to period t. Data on MEAs are obtained from the International Environmental Agreement Database Project.[20] In some specifications, the vector $\mathbf{Z}_{it}^{\prime}$ may also include $Polity_{i,t}$, which measures country $i's$ political orientation (autocracy / democracy) using the Polity2 index from the Polity IV Data Series 2009. The index ranges from -10 to 10, where higher values indicate a stronger level of democracy. It may also include the log of GDP. Table II provides summary statistics of the variables.

We estimate (6) using Probit and ordinary least squares (OLS). Probit results are presented as average marginal effects so that the coefficients can be interpreted as contributions to the probability of Kyoto commitment. Table III reports the results. Column (1) shows that, in a Probit model, a country which has ratified the Rome Statute and is therefore a member of the ICC has a 43.8 percentage points higher likelihood to commit to binding Kyoto commitments. Column (2) adds the spatial lag of ICC membership (i.e., membership of other countries, weighted by their relevance to the country under consideration). The spatial lag not being a dummy variable, the marginal effect is evaluated at the average of that variable. Including it increases the fraction of variance explained from 15 to 41% and the Chi^2-statistic well above the threshold of 10. The average predicted success is 0.680 (the sample mean is 0.675). The ICC membership variables will be excluded from the second-stage equation; the covariates added in column (3) will be included. Log population turns out to be a strong predictor of Kyoto commitments: fast growing economies have a strongly reduced probability to have commitments. Evaluated at the average growth rate (about 4.5%) the gradient of the Probit function is very steep. The log stock of other MEAs, i.e., excluding Kyoto, is a proxy for green preferences. It has a positive influence on ratification of the Kyoto Protocol, but the effect is not statistically significant. The coefficient on the Polity index suggests that an increase in the democratic stance of countries lowers the odds for Kyoto commitments. This is because in the period under considerations many non-committed countries have strongly improved

[20] http://iea.uoregon.edu/page.php?query=list_countries.php

their Polity ratings (Indonesia by 8 points, Mexico by 1.5 points, and Chile by 1.25 points). Finally, the coefficient on log GDP appears with a positive sign, but is statistically insignificant. GDP growth does not predict the ratification of Kyoto commitments.

In our second-stage regressions, we will find that population explains emissions and the carbon footprint with elasticities statistically identical to unity. In our preferred specifications, we therefore work with dependent variables in per capita terms and suppress population from the left-hand side. So, in the following columns, we suppress population. Column (4) shows that the ICC variables continue to explain Kyoto commitment when China is excluded from the sample; column (5) finds the same picture by dropping those transition countries that have become EU members between the pre- and post-treatment periods. Finally, column (6) returns to the full sample, but estimates the equation by OLS (linear probability model). It includes a WTO dummy into the equation (essentially a China dummy). The coefficients on the ICC variables still are significant and have the same signs and magnitudes as in the Probit regressions. Dropping the non-significant covariates moves the F-statistic easily above the threshold of 10.

Columns (7) to (10) introduce a different potential instrument, namely the lag of log population (i.e., between the averages 1993-96 and 1997-2000). Whether controls such as log of GDP or the Polity index are included or not, or whether the full sample is used or whether new EU members are excluded or not, does not change the fact that higher past population growth strongly reduces the likelihood of ratifying Kyoto commitment. The share of variance explained ranges between 68 and 90%. Finally, columns (11) and (12) feature the ICC variables along with past population growth in linear probability models. Own ICC membership and the spatial lag thereof have the expected signs but carry p-values of 0.13 and 0.12, respectively. However, they are jointly significant at the 2% level. The lagged log of population continues to have a strong negative effect. Adding covariates does not change this picture. In both columns, the share of explained variance is about 65% and the F-statistics are well above 25.

Our *identification assumption* is the following: Membership to the ICC is not caused by *growth* in carbon emissions or in the carbon footprint of nations. ICC membership does not directly affect growth in carbon emissions or the carbon footprint, neither.[21] Past population growth is another potential instrument, in particular if we work with dependent variables in per capita terms so that the contemporaneous population lag disappears from the left-hand side regressors. Then, it should not affect contemporaneous changes in emissions or the footprint or be caused by those variables. Since we have more than a

[21]ICC membership may be a proxy for a country's overall preference for multilateralism. Our differences-in-differences strategy accounts for that preference as long as it does not change over time. In our second-stage regressions, we include the stock of other multilateral environmental agreements and membership in the WTO to capture the time-variant component.

single instrument, we can compute overidentification tests to verify whether the instruments are indeed uncorrelated with the error term, and are thus rightfully excluded from the estimated equation.

4 Benchmark results: Kyoto has affected firms but not consumers

Table IV presents our benchmark results. Columns (1) to (6) present OLS estimations, the remaining columns show evidence from IV regressions. In columns (1) to (3) the dependent variables are expressed in absolute terms while columns (4) to (12) express the variables in per capita terms. All regressions are on first-differenced data, where the pre-treatment period is 1997-2000, and the post-treatment period is 2004-07. Standard errors are heteroskedasticity-robust and finite-sample adjusted.[22] All regressions include a constant (not shown).

4.1 OLS estimates

Column (1) of Table IV regresses the log of domestic CO_2 emissions on the Kyoto status dummy variable, the log of population, and the log of GDP. This parsimonious regression explains a surprising 54% of the total variation in emissions. The Kyoto dummy is negative and statistically significant at the 10% level (p-value of 0.06). The estimate implies that Kyoto commitment is associated with a decrease in domestic emissions by about 7.7% (relative to the unobserved counterfactual of no commitment). So, without its commitment the average Kyoto country would have increased its emissions by more than the actual 4% between the pre- and post-treatment period. The estimated elasticity of emissions with respect to population size is 1.1 and statistically significant at the 1% level. The elasticity is statistically identical to unity (the F-test on unity cannot reject with a p-value of 0.72). Hence, population growth translates one-to-one into emission growth. The unitary elasticity of CO_2 emissions with respect to population is a fairly robust finding.[23] The elasticity of emissions with respect to GDP is about 0.38 and statistically significant, thereby replicating the stylized fact that − holding population constant − economic growth reduces the carbon intensity of economies. Squared GDP or population terms do not turn out statistically significant and are therefore excluded.[24] Column (2) turns to the carbon footprint. Here, the estimated effect of Kyoto is positive, smaller in absolute terms, and statistically insignificant. The elasticity of population size is again statistically identical to unity (p-value of 0.94), and the elasticity

[22]The employed STATA routine is described in Schaffer (2005).

[23]See Cole and Neumayer (2004), who have worked with a larger sample and longer time coverage.

[24]The literature on the carbon Kuznets curve has mixed results so far, see e.g. Dinda (2004) and Stern (2004).

on GDP is about 0.43. Squared terms are again irrelevant and are therefore dropped. So, while GDP or population exert very similar effects on domestic emissions and on the carbon footprint, our results suggest that Kyoto did not have a measurable effect on the carbon footprint of nations. Since emissions apparently did go down, Kyoto commitment increased the CO_2 content of imports. Column (3) verifies this conjecture by regressing net carbon imports as a share of domestic carbon emissions on the Kyoto commitment dummy. The point estimate is positive, statistically significant at the 5% level (p-value of 0.03). It implies that Kyoto commitment increases the CO_2 import share by about 11.8 percentage points. Population and GDP both have positive signs but are statistically insignificant. The regression is less successful than the preceeding ones in explaining outcome variance (adjusted R^2 is 0.21). Dropping the insignificant variables slightly reduces the point estimate of Kyoto to 0.11, but lowers the robust standard error to 0.03.

Since the effect on log population in columns (1) to (2) is statistically identical to unity, it is useful to divide the regression equation by the log of population and express the dependent variable in per capita terms. This saves valuable degrees of freedom. Columns (4) to (5) show that this transformation has only a marginal effect on the point estimates of Kyoto commitment, slightly reduces the root mean squared error, and improves the accuracy of estimates. It still holds that Kyoto reduces domestic emissions, increases carbon imports but has not affected the carbon footprint. In most of the remaining analysis, we therefore work with dependent variables defined in per capita terms.

4.2 IV estimates

Regressions (1) to (6) in Table IV assume that the error term is uncorrelated with the Kyoto dummy. As explained before, this is unlikely to be true: countries expecting a downward trend on their emissions may be particularly willing to commit to Kyoto targets so that OLS estimates will be biased away from zero. Hence, an IV approach is needed. At the same time, however, IV estimation also cures measurement error in the Kyoto variable which is possibly large, too: Kyoto commitment is only a very imperfect proxy for countries' carbon policies. This biases OLS estimates toward zero. The net bias is therefore unclear. Column (7) to (12) instrument the Kyoto dummy with the ratification status of the ICC treaty, the spatial lag thereof, and the lagged growth rate of population. In all specifications, we report a battery of diagnostics to check the validity of our IV strategy. In particular, we report the p-value associated to the Hansen test of overidentifying restrictions. The joint null hypothesis is that the instruments are valid, i.e., uncorrelated with the error term, and that the excluded instruments are correctly excluded from the estimated equation. The reported J-statistic is consistent in the presence of heteroskedasticity.[25] Finally, we show the heteroskedasticity-robust Kleibergen-Paap Wald F-statistic on the excluded instruments. Following Stock and Yogo (2005), we report the maximum bias of IV estimation due to weak instruments. The first maximum bias relates to the actual (i.e., different from the undistorted F) maximal size of the Wald test; the second defines weak instruments in terms of the maximum bias of the candidate IV estimator relative to the squared bias of the OLS estimator. The idea is to compare the first-stage F-statistic matrix to a critical value. The critical value is determined by the IV estimator in use, the number of instruments, the number of included endogenous regressors, and how much bias or size distortion the researcher is willing to tolerate. Stock et al. (2002) suggest that an instrument is "weak" if 2SLS *relative bias* exceeds 10% or the actual *size* of the nominal 5% 2SLS t-test exceeds 15%.

In regressions (7) to (9), the F-statistic on the excluded instruments is 29.54, well beyond the canonical 10% and implying the lowest possible maximum biases as of Stock and Yogo (2005). The overidentification test cannot reject the null of instrument validity, while the underidentification test does reject, signalling instrument relevance. Accordingly, it appears that our IV strategy is valid. Compared to the OLS estimates presented in columns (4) to (6), the IV estimates of columns (7) to (9) yield very comparable results. Kyoto decreases domestic emissions by about 8.5%, does not affect the carbon footprint, and drives up net carbon imports by about 14 percentage points.

Columns (10) to (12) implement specifications with additional controls. These more complete regressions are our preferred specifications. An important control is membership in the WTO, a key multilateral institution. In our sample, including a WTO dummy is equivalent to including a China dummy. In both the emissions and the footprint equation that dummy is positive and statistically significant at the 1% level. Ceteris paribus, China's emissions are 30% and its carbon footprint 17% higher than the rest of the world average. Including a control for the degree of democracy of a country's political system (Polity) appears to affect emissions, footprints and net carbon imports positively, carbon footprints being most strongly affected. Reforms that increase the democratic stature of countries often also spur growth. The log of the stock of other (than Kyoto) multilateral environmental agreements is meant to proxy for countries' green preferences. They do not exert a measurable effect, but it is important to note that there is very little time variation in this variable. Finally, we control for EU membership. Domestic emissions are affected negatively, but carbon footprint and net carbon trade are not affected. These additional controls

[25] We also compute an underidentification test of whether the equation is identified, i.e., that the excluded instruments are relevant (correlated with the endogenous regressors). The null hypothesis is that the equation is underidentified. The Kleibergen and Paap (2006) statistic is heteroskedasticity-robust. That test always rejects with p-values lower than 0.01, so that we do not report it to save space.

change the estimated Kyoto effects only very slightly: Kyoto decreases domestic emissions by about 7%, but now appears to increase the CO_2 footprint by about 8.8%. That latter effect is statistically significant at the 10% level (p-value 0.057). The production effect minus the absorption effect approximates the effect on net imports which is now at 16.8 percentage points.[26]

Summarizing, our benchmark IV regressions suggest that Kyoto commitments have a measurable negative effect on CO_2 emissions, but leave the CO_2 footprint either unchanged or higher than in the counterfactual situation. Increased carbon imports from countries with inferior production technologies explain this pattern. Kyoto has affected firms – who have reduced emissions, possibly by outsourcing production to non-committed countries – but not consumers – who have not changed their consumption habits.

5 Robustness checks

The remaining analysis in this paper discusses a wide array of robustness checks ranging from using different country samples to applying alternative IV strategies and treatment windows. Results always compare to columns (10) to (12) of our benchmark Table IV. The thrust of our argument continues to hold: Kyoto has led to increased net imports in committed countries but has not reduced carbon footprints. Results are summarized in Table V; full regression output is found in the web appendix (Tables A1 to A4).

5.1 Alternative samples

Excluding China. Panel A of Table V varies the sample of countries that underly the regressions. In columns (A1) to (A3), we drop China from the sample. One could easily imagine that China's special situation, also due to its entry into the WTO in 2002, drives the pattern discovered in our benchmark regressions. However, quite the opposite is true. While the positive effect of Kyoto commitment on domestic emissions becomes less pronounced (now standing at about 5.4%, measured only at the 10% level of significance (p-value of 0.08)), the carbon footprint of countries now turns out to be affected more strongly and more decisively positively than without China in the sample (now at about 9.7% with a p-value of 0.04). As a consequence, Kyoto pushes net imports of carbon up by 16.1 percentage points. As shown by the overidentification and the weak instruments test, our IV strategy remains valid.

[26]Expressing net carbon imports relative to domestic carbon footprints or refraining from any normalization leads to similar signs and levels of statistical significance.

Excluding transition countries. Columns (A4) to (A6) exclude Germany, Slovakia, Romania, and Poland from the sample. These countries have inherited a substantial industrial production base from formerly centrally planned economies and have also reduced domestic emissions by at least 0.5 percent per year (see Table I). It is often argued that the small overall success of the group of committed countries is an artifact of those transition countries' industrial restructuring, as heavily polluting old plants were replaced by more efficient ones. However, this does not seem to drive our results. Note that our IV strategy identifies the effect of Kyoto against the counterfactual of no Kyoto and not against any specific business-as-usual trajectory. Excluding those transition countries largely confirms our benchmark results: Kyoto has lowered domestic emissions by about 7.7% (p-value 0.04), increased the carbon footprint by about 9.6% (p-value 0.04), and increased net carbon imports by about 18.1 percentage points (p-value 0.00). In all regressions, the F-statistic on excluded instruments remains high (38.14), and the other first-stage diagnostics signal validity of our strategy.[27]

Excluding all ex-communist countries. Finally, columns (A7) to (A9) exclude all eight ex-communist countries from the sample. This decreases the sample size quite a bit and makes inference harder. Also the quality of our instruments is affected. The F-statistic on excluded instruments falls to 12.88, which is, however, still above the alert level of 10. Compared to our benchmark regressions, the lower F-statistic implies that the maximum 2SLS bias relative to the OLS endogeneity bias is now 10% rather than 5% according to the Stock and Yogo (2005) critical values. In terms of results, Kyoto no longer has a measurable impact on domestic CO_2 emissions. The increase in the carbon footprint is now solely driven by an increase in net carbon imports of 15.7 percentage points. The results obtained by excluding the ex-communist countries yields the most pessimistic picture possible: Kyoto appears to have triggered delocation of production to dirtier countries without giving rise to emission savings in committed countries.

5.2 Alternative IV strategies

Using ICC instruments only. In our benchmark regressions, we have used three instruments for the Kyoto dummy: ICC membership, its spatial lag, and lagged population growth. In Panel B of Table V, we assess whether this choice of instruments influences the results. Columns (B1) to (B3) use only the ICC variables as instruments. Stock and Yogo (2005) propose to use *limited information maximum likelihood* (LIML) instead of IV to reduce a possible bias due to weak instruments. The first-stage diagnostics

[27] The overidentification test fails to reject the null of validity at the somewhat marginal 11% level in column (A6).

show that the overidentification (and underidentification test, not reported) yield satisfactory results. The F-statistic on excluded instruments, however, is now only 4.33. This is lower than the Staiger and Stock (1997) 2SLS rule of thumb which requires a minimum value of 10 for a strong instrument.[28] Stock and Yogo (2005) show that this rule is too conservative with LIML estimation. Their tabulations imply that the true power of the F-test is 20%, which is large (but not excessive). This IV strategy biases the absolute value of Kyoto estimates upwards. The pattern discovered in our benchmark table, however, remains intact: Kyoto reduces domestic emissions, increases carbon imports, and has no effect on the carbon footprint.

Lagged population growth as only instrument. Next, we use a single instrument only, namely lagged population growth (columns (B4) to (B6)). The F-statistic on the excluded instrument is large, so that the instrument appears strong. The idea of the instrument is that lagged population growth correlates with countries' willingness to commit to climate goals, but not to current emission growth. The effect of current population growth on emission increases is captured by expressing the dependent variables in per capita terms. This IV strategy yields estimates of the Kyoto effect close to the benchmark estimates.

Wooldridge two-step procedure. Finally, columns (B7) to (B9) apply a procedure proposed by Wooldridge (2002, p. 623 f.). It consists in estimating the binary response model (3) in Table III by maximum likelihood (Probit),[29] and obtain the fitted probabilities $\hat{\Pi}$. The variable $\hat{\Pi}$ is then used as an instrument in a standard IV approach. The F-statistic on the excluded instrument is 54.73, so that the instrumental variable appears strong. We find again that Kyoto commitment reduces domestic emissions (by about 8.3%), has a weakly significant but positive effect on the carbon footprint, and increases net imports of CO_2.

5.3 Alternative definitions of the dependent variables

Carbon intensities. Panel C of Table V varies the definition of the dependent variables. In columns (C1) and (C2), emissions are relative to GDP. As shown by the first-stage diagnostics, this modification keeps the IV strategy intact. Compared to the benchmark regressions, the sign pattern of coefficients is fairly

[28] The maximum relative bias test cannot be performed in these regressions since the equations are not "sufficiently" overidentified, see Stock and Yogo (2005).

[29] Using a linear model yields comparable results, but the obtained instrument is somewhat less powerful. The choice of a non-linear selection model helps with identification of the Kyoto effects.

similar. Instead of including GDP, we use GDP per capita whenever the dependent variable is in per GDP terms. It turns out that higher GDP per capita has a strong negative influence on emission intensities. Richer countries have higher emissions per capita, but lower emission intensities (see also Cole and Neumayer, 2004). The effect of Kyoto commitment on the CO_2 intensity of production is negative and statistically significant at the 5% level (p-value 0.02): Kyoto reduces that intensity by 7.6%. In line with our results on emissions per capita, Kyoto has no measurable effect on the CO_2 intensity of absorption; the point estimate is positive but statistically insignificant (p-value 0.13). Net carbon imports are again positively affected.

Computing carbon footprints holding I-O tables fixed. Columns (C4) to (C6) apply a different method in calculating the carbon footprint. Rather than using new I-O tables when they are available, they are now held fixed to the year 2000. This modification has no importance for measured domestic CO_2 emissions, but affects the calculation of the carbon footprint and net carbon imports. In column (C4), the carbon footprint is expressed in per capita terms; in column (C5) it is expressed in CO_2 intensity terms. In both cases, the estimated effect of Kyoto is positive but statistically zero (p-values of 0.23 and 0.42, respectively). Coefficients on controls do not change much relative to the benchmark regressions. Column (C6) shows that Kyoto still exerts a positive, statistically significant effect on net carbon imports (p-value of 0.003), comparable in size to the benchmark estimates.

Alternative treatment of rest-of-the-world. In the benchmark regressions, we treat the technology matrix of the RoW aggregate as an average over observed countries.[30] In the robustness checks presented in columns (C7) to (C9), we instead assume that the RoW has the US technology matrix. Assuming US technology has some tradition in the empirical factor content of trade literature (see Feenstra (2004) for a survey) and often has important implications for results. In the present context, however, this assumption makes little difference to the interesting coefficients: Kyoto has a positive effect on countries' per-capita carbon footprint (column C7), but no measurable effect on absorption per GDP (column C8). Net carbon imports (column C9) are still affected positively.

5.4 Alternative treatment windows

In the benchmark regressions, we defined the treatment window to comprise the years 2001-03. In this window, most countries have, if at all, ratified the Kyoto Protocol. In Panel D of Table V we perform

[30] See Section 2 for details.

robustness checks pertaining to this choice. We keep pre- and post-treatment windows of similar length.[31]

Narrow treatment window. We start by looking at the results when we define the pre-treatment period to be 1997-2001 and the post-treatment period to be 2003-07. The treatment window, i.e., the period over which the Kyoto dummy switches from zero to unity is then confined to the year of 2002.[32] Columns (D1) to (D3) of Panel D show that the Kyoto effects on emissions, footprints, and net imports are very much in line with the benchmark results; also the coefficients on covariates vary only a bit. The IV strategy is valid for emissions and footprint as the dependent variable; the Hansen overidentifying test, however, rejects at the 10% level when the dependent variable is net imports, therefore casting doubts over the validity of the instruments in this case.[33] The estimated effect of Kyoto, however, does not deviate strongly from our benchmark case. Eliminating the MEA variable leads the Hansen test not to reject any more.

Broad treatment window. Next, we define the pre-treatment period to be 1997-2000 and the post-treatment period to be 2004-07. The resulting wide treatment window now comprises all ratifications (except that of Australia). The sign pattern obtained from regressions presented in columns (D4) to (D6) compares well to the benchmark results. As before, the Hansen test narrowly rejects in the net imports specification.

Treatment at start of year 2005. Finally, we assume that treatment started in the beginning of the year 2005 when the Kyoto Protocol formally entered into force.[34] The pre-treatment period then is 2002-04 while the post-treatment period is 2005-07. With this definition, the IV strategy is valid for all dependent variables: the F-statistic on excluded instruments is higher than 100, and the Hansen test cannot reject instrument validity. The resulting point estimates of Kyoto commitment are estimated at satisfactory precision for emissions and net imports. Domestic emissions go down by about 6.3%, while net imports as a share of domestic emissions increase by about 7.9 percentage points.

[31] In principle, we could define the pre-treatment window always as starting in 1995. We have tried this in additional robustness checks: results do not change. However, we prefer to compute averages over symmetrically defined periods.

[32] Switzerland, Romania and Russia are still coded as treated.

[33] When expressing the dependent variable as the share of domestic carbon consumption, the overidentification test does not reject any more; the point estimate is comparable.

[34] The Protocol became legally binding after Russia's ratification pushed the share of world emissions as of 1990 covered by Kyoto over the 55% threshold. The EU, Japan, and Canada and other countries had declared earlier on that they would treat the emission reduction targets as binding even in the absence of Russia's ratification.

5.5 Additional robustness checks

We have also experimented with a balanced panel of yearly observations. Results are reported in Table A5 in the web appendix. The first 6 columns use the within transformation to control for unobserved time-invariant country-specific determinants of emissions. Columns (1) to (3) present OLS estimates, while columns (4) to (6) apply our benchmark IV strategy to this setup. Not surprisingly, with dramatically increased degrees of freedom (we now have 520 observations), it is possible to calculate Kyoto effects at higher statistical precision. The OLS estimates suggest that Kyoto has decreased domestic CO_2 emissions by about 2.9%, increased the carbon footprint by about 3.6%, and led to higher net carbon imports by 8 percentage points. The signs of the covariates are sensible; note that our proxy for green preferences (the number of MEAs other than Kyoto ratified by a country) now reduces the carbon footprint. Turning to IV estimates in columns (4) to (6), the sign pattern of Kyoto coefficients is preserved. Point estimates increase, reflecting the presence of important measurement error in the Kyoto variable. Instrumenting does not alter the estimated coefficients on covariates much. The IV strategy appears valid, with the over- and underidentification tests yielding good results and the F-statistic on excluded instruments at 81.48.[35]

6 Conclusion

We have estimated the effect of Kyoto commitments on domestic CO_2 emissions, carbon footprints and net carbon imports. We have done so by exploiting a newly constructed panel data set of yearly observations from 1995-2007 for 40 countries. Our inference is based on the differences between committed and non-committed countries over two time periods: a pre-treatment period of 1997-2000 and a post-treatment period of 2004-07. This differences-in-differences approach is demanding as it is effectively based on a cross-section of only 40 rates of change. We use an IV strategy that exploits correlation between countries' commitment to Kyoto and that to the International Criminal Court, as well as lagged population growth. We find a robust pattern in the data: On average, Kyoto commitment has reduced domestic emissions by about 7%. It has not consistently affected the carbon footprint. The difference between production and absorption being made up by international trade, Kyoto commitment has increased the ratio of net carbon imports over domestic emissions by about 17 percentage points.

[35] Estimation based on first-differenced yearly data is less successful. The OLS model does not reveal any impact of Kyoto commitment on outcome variables. The IV model resurrects the sign pattern that we have seen throughout the tables of this paper (domestic emissions down, footprint unchanged, net imports up), but instruments appear too weak in the context of yearly differenced data.

Our results imply that the Kyoto Protocol has given rise to substantial relocation of production (carbon leakage). Committed countries have reduced their emissions relative to the counterfactual of no Kyoto, but they have not reduced their carbon footprints. Some of our estimates even suggest the opposite. It follows that the Kyoto Protocol, due to its incomplete coverage, has been ineffective or possibly even harmful for the global climate. It has imposed substantial costs on firms and consumers in committed countries, but the return of all these efforts – lower global carbon emissions – has been statistically indistinguishable from zero. Our results lend empirical support to the case that unilateral climate policies bear very little promise. Either future global climate deals have to cover all major economies, or committed countries have to apply border tax adjustments to contain the carbon leakage problem.

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Table I: Per capita emission levels and carbon trade: initial levels and rates of change

Country	Year of ratifi-cation	CO2 emissions		CO2 footprint		Net CO2 imports as % of emissions	
		1995	avg. yearly growth rate	1995	avg. yearly growth rate	1995	2007
India		0,85	2,65%	0,71	3,19%	-16,9%	-11,3%
Indonesia		0,97	4,19%	1,02	2,97%	4,9%	-9,4%
Brazil		1,46	1,69%	1,46	2,06%	0,0%	4,5%
China		2,46	5,16%	2,17	3,25%	-11,5%	-29,5%
Turkey		2,46	3,03%	2,59	1,74%	5,3%	-9,8%
Chile		2,91	3,36%	3,21	2,83%	10,1%	3,4%
Mexico		3,33	1,58%	2,87	3,01%	-13,9%	2,3%
Argentina		3,35	1,60%	3,44	1,15%	2,7%	-2,7%
Portugal	2002	4,80	0,64%	5,37	1,32%	11,9%	21,4%
Romania	2001	5,16	-1,86%	4,85	-0,54%	-6,0%	10,1%
Hungary	2002	5,56	-0,22%	5,31	1,03%	-4,5%	10,9%
Switzerland	2003	5,73	-0,22%	11,33	1,93%	97,7%	155,9%
Spain	2002	5,88	3,09%	6,21	3,74%	5,7%	14,2%
France	2002	5,92	-0,18%	7,10	0,88%	19,9%	36,1%
Sweden	2002	6,48	-1,97%	7,60	0,77%	17,3%	63,0%
South Africa		6,56	0,72%	5,30	0,18%	-19,1%	-24,2%
New Zealand	2002	6,69	2,08%	7,60	1,23%	13,7%	2,7%
Slovenia	2002	6,91	1,14%	5,92	2,20%	-14,3%	-2,6%
Greece	2002	6,96	2,27%	7,32	3,19%	5,2%	17,4%
Italy	2002	7,15	0,42%	7,44	1,10%	4,0%	12,9%
Austria	2002	7,30	1,26%	9,15	1,07%	25,3%	22,4%
Norway	2002	7,53	0,49%	10,10	1,66%	34,2%	54,4%
Slovak Republic	2002	7,62	-1,00%	7,04	1,02%	-7,6%	17,7%
Korea, Rep.		8,09	1,88%	7,72	2,31%	-4,5%	0,5%
Poland	2002	8,58	-0,68%	7,38	-0,31%	-14,0%	-10,2%
Israel		8,65	0,71%	9,91	-0,22%	14,5%	2,4%
United Kingdom	2002	8,88	-0,27%	8,00	0,42%	-9,9%	-2,2%
Ireland	2002	9,13	1,35%	10,99	3,76%	20,4%	60,6%
Japan	2002	9,15	0,49%	10,50	0,05%	14,8%	8,9%
Germany	2002	10,65	-0,78%	11,70	-0,67%	9,9%	11,4%
Russian Federation	2004	10,66	0,43%	9,28	1,51%	-12,9%	-0,9%
Finland	2002	10,97	0,95%	9,33	1,45%	-15,0%	-9,8%
Denmark	2002	11,01	-1,47%	12,69	-0,40%	15,3%	31,1%
Estonia	2002	11,06	1,79%	7,37	4,79%	-33,4%	-4,6%
Netherlands	2002	11,08	-0,07%	14,99	0,95%	35,3%	52,8%
Czech Republic	2001	12,00	-0,04%	8,83	0,24%	-26,4%	-23,8%
Belgium	2002	12,14	-0,65%	12,37	0,38%	1,8%	15,3%
Canada	2002	15,67	0,87%	16,02	1,06%	2,3%	4,6%
Australia	2007	15,87	1,55%	12,73	1,96%	-19,7%	-15,6%
United States		19,26	-0,05%	19,48	0,41%	1,2%	6,8%

Notes: The 40 sample countries ordered with respect to their 1995 per capita emission levels. CO_2 emissions and footprints in tons of CO_2 per capita. Grey shades indicate countries in which the carbon footprint has fallen. Domestic CO_2 emissions are from the IEA. Carbon footprints computed using MRIO approach and approximating RoW I-O tables with the GDP per capita matching method described in the text.

Table II: Summary statistics

Variable	Mean	Std. Dev.	Min	Max	Source
Log CO2 emissions (per capita)	0.05	0.11	-0.15	0.50	iea.int
Log CO2 footprint (per capita)	0.10	0.10	-0.12	0.32	
Net CO2 imports, share of emissions	0.05	0.10	-0.18	0.29	
Kyoto commitment dummy	0.68	0.47	0.00	1.00	unfccc.int
ICC dummy	0.68	0.40	0.00	1.00	treaties.un.org
ICC dummy, spatial lag	0.52	0.63	0.01	2.65	
log population, time lag	0.03	0.03	-0.05	0.10	PWT 7.0
Log GDP	0.42	0.13	0.23	0.83	PWT 7.0
EU dummy	0.15	0.36	0.00	1.00	
WTO dummy	0.04	0.17	0.00	1.00	wto.org
Polity IV	0.44	1.36	-1.00	8.00	www.systemicpeace.org
Log stock of other MEAs	0.28	0.14	0.13	0.72	iea.uoregon.edu

Notes: The table shows changes between pre-treatment (1997-2000) and post-treatment (2004-07) period.

Table III: Explaining Kyoto commitment

Dep.var.:	Kyoto commitment											
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
Method	Probit	Probit	Probit	Probit	Probit	OLS	Probit	Probit	Probit	OLS	OLS	OLS
Sample	full	full	full	CHN excl.	trans. excl.	full	full	full	trans. excl.	full	full	full
Excluded instruments												
ICC (0,1)	0.438***	0.266***	0.168**	0.244**	0 .304**	0.362*					0.185	0.137
	(0.114)	(0.113)	(0.080)	(0.119)	(0.145)	(0.200)					(0.119)	(0.130)
ICC, spatial lag		0.776***	0.670***	0.860***	0 .883**	0.235**					0.086	0.108*
		(0.223)	(0.189)	(0.285)	(0.359)	(0.118)					(0.054)	0.0563)
Log population, time lag							-9.058***	-15.017***	-17.667***	-12.53***	-10.90***	-11.56***
							(1.054)	(4.552)	(5.368)	(1.291)	(1.917)	(1.461)
Other covariates												
Log population			-4.252***									
			(0.743)									
Log stock of other MEA			0.061	-0.568	-0.593	0.238						-0.428
			(0.564)	(0.522)	(0.670)	(0.484)						(0.269)
Polity IV (-10 to 10)			-0.170**	-0.094	-0.052	-0.048		-0.392***	-0.461***	-0.060***		-0.057*
			(0.087)	(0.090)	(0.097)	(0.026)		(0.136)	(0.160)	(0.012)		(0.028)
Log GDP			0.105	0.588	0.224	0.181		-0.304*	-0.358***	-0.671**		
			(0.233)	(0.685)	(0.548)	(0.855)		(0.149)	(0.176)	(0.292)		
WTO (0,1)						-0.314						
						(0.398)						
Predictive margin	0.673***	0.680***	0.676***	0.699***	0.623***		0.675***	0.675***	0.618***			
	(0.067)	(0.055)	(0.038)	(0.054)	(0.063)		(0.031)	(0.021)	(0.025)			
Pseudo R^2/adj. R^2	0.149	0.413	0.691	0.424	0.376	0.220	0.800	0.904	0.893	0.679	0.645	0.664
F/Chi^2-stat	6.978	12.46	13.11	8.999	9.917	9.343	12.07	17.01	16.94	61.01	26.13	29.77

Notes: First-differenced model. N=40 countries, T=2: pre-treatment (1997-2000), post-treatment average (2004-07). Spatial Kyoto lag: size and distance weighted ICC status of other countries. All regressions include a constant. Heteroskedasticity-robust standard errors. * p<0.1,** p<0.05, *** p<0.01. Probit models: average marginal effects reported; robust standard errors calculated using the delta method.

Table IV: The effects of Kyoto on carbon emissions, footprint and net imports – Benchmark results

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
	Log levels of CO2 ...			Log *per capita* values of ...								
Dep.var.:	**emissions**	**fooprint**	**imports#**	**emissions**	**fooprint**	**imports#**	**emissions**	**fooprint**	**imports#**	**emissions**	**fooprint**	**imports#**
Method	FD-OLS	FD-OLS	FD-OLS	FD-OLS	FD-OLS	FD-OLS	FD-2SLS	FD-2SLS	FD-2SLS	FD-2SLS	FD-2SLS	FD-2SLS
Kyoto (0,1)	-0.077*	0.015	0.118**	-0.085***	0.017	0.112***	-0.085**	0.053	0.138***	-0.070**	0.088*	0.168***
	(0.040)	(0.046)	(0.051)	(0.028)	(0.037)	(0.030)	(0.032)	(0.044)	(0.037)	(0.033)	(0.045)	(0.044)
Log population	1.129***	0.965**	0.094									
	(0.359)	(0.476)	(0.581)									
Log GDP	0.375**	0.434***	0.063	0.367**	0.436***	0.057	0.367**	0.456***	0.071	0.129	0.338**	0.205
	(0.162)	(0.094)	(0.133)	(0.159)	(0.090)	(0.121)	(0.159)	(0.093)	(0.115)	(0.091)	(0.125)	(0.148)
WTO (0,1)										0.304***	0.170***	-0.119
										(0.083)	(0.060)	(0.093)
Polity IV (-10 to 10)										0.0149*	0.031***	0.013*
										(0.008)	(0.006)	(0.006)
Log stock of other MEA										0.106	0.021	-0.139
										(0.114)	(0.127)	(0.147)
EU (0,1)										-0.071*	-0.070	-0.006
										(0.035)	(0.063)	(0.060)
2nd stage diagnostics												
adj. R2	0.535	0.310	0.213	0.375	0.263	0.233	0.375	0.235	0.218	0.550	0.354	0.189
F-stat	14.88	11.13	4.49	5.29	13.56	6.93	4.69	12.91	7.03	11.24	46.30	3.35
RMSE	0.085	0.090	0.089	0.083	0.088	0.088	0.083	0.090	0.089	0.071	0.083	0.090
1st stage diagnostics												
Over-ID test (Hansen J; p-val.)							0.192	0.599	0.174	0.227	0.770	0.125
Weak ID test (F-stat)							29.54	29.54	29.54	34.95	34.95	34.95
Max 2SLS F-test size bias##							10%	10%	10%	10%	10%	10%
Max 2SLS bias rel. to OLS##							5%	5%	5%	5%	5%	5%

Notes: First-differenced models. N=40 countries, T=2 : pre-treatment average (1997-2000), post-treatment average (2004-07). All regressions include a constant (not shown). Standard errors and 1st stage diagnostics are heteroskedasticity-robust and finite-sample adjusted. * $p<0.1$,** $p<0.05$, *** $p<0.01$. Excluded instruments for Kyoto variable: ratification status of ICC treaty, spatial lag thereof, and lagged growth rate of population. 2SLS (two stage least squares). Robust underidentification test (not reported) satisfied in every regression.

#Net carbon imports as a share of domestic carbon emissions.

##Stock and Yogo (2005); critical values are for Cragg-Donalds F-statistic and i.i.d. errors.

Table V: Robustness checks – Summary table IV estimates

PANEL A: Alternative Samples

Sample	China excluded			GER, ROM, POL, SVK excl.			Ex-communist countries excl.		
	emissions	footprint	imports#	emissions	footprint	imports#	emissions	footprint	imports#
	(A1)	(A2)	(A3)	(A4)	(A5)	(A6)	(A7)	(A8)	(A9)
Kyoto (0,1)	-0.054*	0.097**	0.161***	-0.077**	0.096**	0.181***	0.010	0.144***	0.157***
	(0.030)	(0.045)	(0.043)	(0.035)	(0.044)	(0.045)	(0.037)	(0.046)	(0.050)
Over-ID test (p)	0.235	0.728	0.153	0.443	0.533	0.110	0.237	0.789	0.203
Weak ID test (F)	33.160	33.160	33.160	38.140	38.140	38.140	12.880	12.880	12.880

PANEL B: Alternative IV strategies

Instrument(s):	ICC variables only (LIML)			Lagged population growth			Selection probability		
	emissions	footprint	imports#	emissions	footprint	imports#	emissions	footprint	imports#
	(B1)	(B2)	(B3)	(B4)	(B5)	(B6)	(B7)	(B8)	(B9)
Kyoto (0,1)	-0.138**	0.095	0.285***	-0.066*	0.089*	0.162***	-0.083**	0.070*	0.173***
	(0.066)	(0.057)	(0.097)	(0.033)	(0.046)	(0.045)	(0.033)	(0.038)	(0.043)
Over-ID test (p)	0.6360	0.4760	0.3470						
Weak ID test (F)	4.327	4.327	4.327	99.110	99.110	99.110	54.730	54.730	54.730

PANEL C: Alternative dependent variables

Dep.var.:	variables per unit of GDP			Fixed I-O Tables (1995)			US I-O Tables for RoW		
	emissions	footprint	imports#	footprint	footprint##	imports#	footprint	footprint##	imports#
	(C1)	(C2)	(C3)	(C4)	(C5)	(C6)	(C7)	(C8)	(C9)
Kyoto (0,1)	-0.076**	0.064	0.136***	0.062	0.039	0.136***	0.089*	0.064	0.167***
	(0.032)	(0.041)	(0.037)	(0.051)	(0.047)	(0.043)	(0.045)	(0.041)	(0.044)
Over-ID test (p)	0.333	0.722	0.337	0.398	0.521	0.223	0.777	0.723	0.127
Weak ID test (F)	36.54	36.54	36.54	34.95	34.95	34.95	34.95	34.95	34.95

PANEL D: Alternative treatment windows

Window:	narrow: 2002 only			broad: 2001-2004			treatment at start of year 2005		
	emissions	footprint	imports#	emissions	footprint	imports#	emissions	footprint	imports#
	(D1)	(D2)	(D3)	(D4)	(D5)	(D6)	(D7)	(D8)	(D9)
Kyoto (0,1)	-0.053**	0.077*	0.135***	-0.085**	0.091*	0.189***	-0.063**	0.011	0.079**
	(0.026)	(0.038)	(0.040)	(0.038)	(0.047)	(0.047)	(0.030)	(0.035)	(0.033)
Over-ID test (p)	0.161	0.692	0.092	0.211	0.711	0.0901	0.325	0.293	0.328
Weak ID test (F)	35.18	35.18	35.18	34.26	34.26	34.26	100.2	100.2	100.2

Notes: N=40 countries, T=2. Default specification: pre-treatment average (1997-2000), post-treatment average (2004-07); excluded instruments for Kyoto variable: ratification status of ICC treaty, spatial lag thereof, and lagged growth rate of population; 2SLS (two stage least squares). All regressions include the full list of covariates as in columns (10) to (12) in Table III and a constant (not shown). Full regression output in Tables A1 to A4 in the web appendix. Standard errors and first-stage diagnostics are heteroskedasticity-robust and finite-sample adjusted. * $p<0.1$,** $p<0.05$, *** $p<0.01$.
Net carbon imports as a share of domestic carbon emissions. ## Footprint per GDP.

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