Climate Change Policy
and
Patterns of International Trade

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November, 2019

Abstract

This paper analyzes the relationship between climate change policies and international trade flows. Using data on carbon dioxide (CO_2) emissions intensities for disaggregated industries and U.S. imports from 1990 to 2010, I find that committing to a quantified emissions target under the Kyoto Protocol is associated with a country exporting less to the U.S. in emissions-intensive industries. This effect is quantitatively important and is comparable to that of factor endowments on comparative advantage. Moreover this pattern is not present prior to the adoption of the Kyoto Protocol, but only emerges as it went into effect. On the other hand, there is little evidence that non-committed countries are specializing in more emissions-intensive industries.

JEL Classification Codes: F18, Q54, Q56

Keywords: international trade; climate change; Kyoto Protocol; CO_2 emissions intensity.

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*Swarthmore College. Email: twang1@swarthmore.edu. I thank Gene Grossman, Stephen Redding and Michael Oppenheimer for their generous support and thoughtful guidance. I have benefited from insightful comments made by participants at the International Trade seminars and the Science, Technology and Environmental Policy (STEP) PhD seminars at Princeton University. I thank the International Economics Section (IES) and Princeton Environmental Institute (PEI) at Princeton University for their generous financial support.

1 Introduction

Climate change is one of the greatest challenges of our time. Deep and rapid cuts in global greenhouse gas (GHG) emissions are required to prevent dangerous anthropogenic interference with the climate system.[1] Since the GHG emissions are a global public bad, efficient mitigation efforts must entail international coordination. However, international cooperation in the form of a global cap or a universal tax on emissions is hard to achieve. Despite agreeing to a common goal in the Paris Agreement, implementation of the agreement relies on individual countries' actions, known as nationally determined contributions (NDCs). While this is an improvement on the Kyoto Protocol, under which a group of industrialized countries unilaterally committed to reduce emissions, a system that depends on nationally determined policies invariably suffers from free rider problems and can lead to unwelcome side effects such as carbon leakage, i.e., emissions reduced by committed countries are offset by increases elsewhere resulting from linkages in global economic activities. Policy makers have also been worried about potential negative effects on the competitiveness of domestic companies in emissions-intensive industries exposed to international trade. On the other hand, there is wide-spread skepticism on the effectiveness of the Kyoto Protocol in reducing emissions. It is therefore useful to assess whether the carbon leakage and competitiveness concerns are supported by data.

In this paper I analyze empirically whether climate change policies have had an effect on the organization of economic activities. In particular, I explore whether the stringency of a country's climate change policies is an important determinant of comparative advantage in international trade. The channel that I consider builds on the well-established insight that differences in the stringency of environmental regulations across countries may result in pollu-

[1] Governments have agreed to the goal of holding the increase in global average temperature below 2, preferrably to 1.5 degrees Celsius, above pre-industrial levels in the Paris Agreement that enterred into force in 2016. In order to achieve this target, there must be substantial emissions reductions over the next few decades and near zero emissions of CO_2 and other long-lived greenhouse gases by the end of the century (Intergovernmental Panel on Climate Change (IPCC), 2014).

tion havens. Since countries with less stringent climate change policies have a lower implied price of GHG emissions, they will have a comparative advantage in producing goods that are more emissions intensive. Thus, the variation in the composition of production and trade associated with the tightening of climate change policies constitutes an important channel for carbon leakage and reflects competitiveness effects.

I examine the aforementioned hypothesis by testing whether countries that commit to a quantified emissions target under the Kyoto Protocol export relatively less in industries that are more emissions intensive. I use detailed data on U.S. imports from 1990 to 2010 and carbon dioxide (CO_2) emissions intensity data for over 200 disaggregated industries for the analysis.[2] In cross-sectional specifications for years after the Kyoto Protocol went into effect, I find that countries with emissions targets under the Protocol export less to the U.S. in more emissions-intensive industries compared to those without commitment. The magnitude of this relationship is comparable to that of traditional determinants of comparative advantage, namely the relative factor endowments. One potential concern for such an analysis is that the countries that commit to emissions abatement could have already been specializing in cleaner industries prior to the Kyoto Protocol for reasons other than climate change policies. The panel structure of the trade data allows me to analyze data from the years preceding and after the introduction of the Kyoto Protocol. I find little evidence that the committed countries specialized in less emissions-intensive industries prior to the adoption of the Kyoto Protocol. Rather, this pattern emerged as countries signed and ratified the Protocol. This is consistent with the view that the commitment have entailed more stringent domestic climate change policies and the resulting higher implied price for GHG emissions have made the countries' comparative advantage shift away from emissions-intensive industries. Contrary to the belief that it is a failed treaty, the Kyoto Protocol is associated with a sizable shift in the composition of trade of the commit-

[2] CO_2 is the most important type of greenhouse gases. It represents 77% of total anthropogenic GHG emission in 2004 measured in CO_2-equivalent in terms of global warming potential (IPCC, 2007).

ted countries. On the other hand, there is little evidence that uncommitted countries have moved toward specializing in emissions-intensive industries, suggesting that the forces of production relocation might not have been fully at work.

The rest of the paper is organized as follows. The next section provides some background information on the Kyoto Protocol and briefly reviews relevant theoretical and empirical literature on international trade and the environment. Section 3 discusses the empirical strategies and the estimation equations. Section 4 describes the data used in the analysis. Section 5 reports the cross-sectional estimation while Section 6 tackles the issue of endogeneity. The last section concludes.

2 Background and Related Literature

The Kyoto Protocol is an international agreement linked to the United Nations Framework Convention on Climate Change (UNFCCC). It was adopted at the third session of the Conference of Parties (COP3) of the UNFCCC in December 1997. By 2010, there are 193 Parties to the Protocol, including 192 States and the European Union (E.U.). The major feature of the Protocol is that it sets quantified emissions targets for the Annex I Parties to the UNFCCC, which include 40 industrialized countries and the E.U. Table 1 lists the countries that are Annex I Parties and reports the targets specified in the Kyoto Protocol.[3] They have committed themselves to national or joint reduction targets, that range from a joint reduction of eight percent for the E.U.,

[3]Since these targets are specified in the Annex B to the Kyoto Protocol, the committed countries are sometimes referred to as the Annex B parties. I will use the term Annex I throughout this paper to denote committed countries unless otherwise specified. The Annex I countries in this paper refers to the Annex I Parties that are committed to a quantified emissions target under the Kyoto Protocol. It differs from the list of current Annex I members to the UNFCCC as it does not include the U.S., Malta and Turkey. The U.S. is not a Party to the Kyoto Protocol. Malta was not an Annex I party when it ratified the Protocol and Turkey is recognized as in a situation different from that of other Annex I Parties. They are not committed to emissions targets under the Protocol.

seven percent for the U.S.,[4] six percent for Japan and zero percent for Russia. These targets amount to a reduction of total emissions from the Annex I countries of about five percent against 1990 levels over the five-year period 2008-2012[5]. The Protocol adopts the principle of "common but differentiated responsibilities,"[6] so that developing countries, including major emitters like China or India, do not face any binding emissions limits.

The Kyoto Protocol has been criticized for its lack of credible punishment. Like most international treaties, the explicit consequences for noncompliance are weak compared to domestic law (Grubb, 2003) and many have worried that it wold not be successful in delivering the promised reduction in emissions, especially without the participation of the U.S. Nonetheless, a quick look at the total fossil-fuel related CO_2 emissions data in the past 20 years (Boden, Marland, & Andres, 2011) suggest that the UNFCCC and the Kyoto Protocol may have had some effect on overall emissions after all. Figure 1 shows that the total emissions from the Annex I countries (including the U.S.) have experienced much slower increase in the last two decades compared to that from the non-Annex I countries and it seemed to have peaked in 2005, when the Kyoto Protocol went into force. In 1990, total emissions from the non-Annex I countries were about half of the Annex I emissions; by 2006, the non-Annex I countries were emitting more than the Annex I countries, and their emissions have continued to grow. Figure 2 offers a closer look at the emissions from different groups of countries. The Annex I countries with economies in transition (EIT) experienced a large decrease in emissions in the 1990s due to

[4]The U.S. originally signed the Kyoto Protocol in 1998, however, it did not ratify the protocol after a non-binding senate resolution (the Byrd-Hagel resolution) urged the Clinton administration to not accept any treaty that did not include "meaningful" participation of all developing as well as industrialized countries, arguing that to do so would unfairly put the U.S. at a competitive disadvantage.

[5]In 2012, the Doha Amendment to the Kyoto Protocol was adopted for a second commitment period, starting in 2013 and lasting until 2020. However, the Doha Amendment has not yet entered into force .

[6]Article 3.1 of the UNFCCC states, "(t)he Parties should protect the climate system for the benefit of present and future generations of humankind, on the basis of equity and in accordance with their common but differentiated responsibilities and respective capabilities." Accordingly, the developed country Parties should take the lead in combating climate change and the adverse effects thereof.

the decline of their economy, which also explains the decrease in total Annex I emissions in that period. Nonetheless, emissions from other Annex I countries with Kyoto commitment, as well as that from the U.S., have increased much more slowly than the non-Annex I countries. The increase became even slower in the early 2000s and eventually the emissions level peaked in 2005 or 2006. On the other hand, emissions from the non-Annex I countries have increased dramatically, with China soaring to overtake the U.S. to become the largest emitter in the world by 2006. The increase in emissions from other non-Annex I countries seems to have sped up in the 2000s as well. This observed difference in the evolution of emissions from different groups of countries and the peaking of the Annex I emissions are consistent with the idea that commitments made by the Annex I countries under the Kyoto Protocol and in the UNFCCC process in general are indeed associated with efforts to mitigate GHG emissions and helped slow down and eventually revert the growth of emissions in these countries. Meanwhile, these unilateral policies may have contributed to speeding up the growth of the non-Annex I emissions through carbon leakage. There are many possible interpretations, such as the faster integration of the global economy in the past two decades or the natural outcome of the stages of development for the countries. Nonetheless, it at least offered hope for finding an effect of the climate change policies.

In recent years, there has been increased interest from policy makers on the interaction of international trade and the global GHG mitigation effort, since trade can have potentially large yet ambiguous effects on the effectiveness of domestic and global climate change policies. Carbon leakage through "dirty" industry relocation to and lower energy prices in non-participating countries has been an important concern for the committed Parties to the Kyoto Protocol. If the climate change policy in a country raises local costs associated with emissions, then another country with a more relaxed policy may have a comparative advantage in industries where such costs are substantial. If demand for these goods remains the same, production may move offshore to the cheaper country with lower standards, and global emissions will not be reduced. This constitutes a composition effect, and is the channel that I will focus on in the current study. Closely related is the technology effect stemming from the large differences in emissions intensities of the production process across countries.[7] The countries with less stringent policies are usually less developed and may employ out-dated and more emissions-intensive technologies, generating more emissions for the same amount of good produced and further contributing to leakage. Lastly, on the supply side, if environmental policies in one country add a premium to certain fuels or commodities, then the demand may decline and their prices may fall. Countries that do not place a premium on those items may then pick up the demand and use the same supply, negating any benefit (Sinn, 2008).

On the other hand, despite all these concerns, various studies have suggested that the presence of international trade provides more benefit than harm for combating climate change. In theory, in an environment with global commitment, international trade in goods may substitute for trade in emissions permits and facilitate more efficient emissions reduction by aligning abatement costs across countries (Copeland & Taylor, 2001; 2005). With the tradable nature of environmental technologies, international trade and foreign direct investment (FDI) serve as conduits of technology diffusion to developing countries (Chua, 1999). In addition, pressure from enhanced environmental regulations and product standards from developed-world importers encourages more stringent environmental policy enforcement and compliance and induces technological upgrading and innovation by the developing-world producers (Zeng & Eastin, 2007; Frankel, 2009).

With both sides seemingly plausible, it will be useful to empirically estimate the actual effect of existing climate change policies in relation to international trade. So far, there has been little empirical evidence for the pollution

[7] The differences may arise because of the varying access to clean technologies among countries. Chua (1999) surveys the literature and summarizes evidence that there are technological innovations that greatly reduce emissions intensities for a wide range of pollutants including CO_2. The differences may also be a reflection of the different composition of a country's energy sources, ranging from the different types of fossil fuels to renewable sources or nuclear power (Douglas & Nishioka, 2009). Another source of difference for empirically measured sectoral emissions intensities across countries is the different within-sector composition of sub-industries or goods with varying emissions intensities.

haven hypothesis with respect to GHG emissions, yet the potential for carbon leakage under deepening regulations cannot be ruled out. With the first and only agreed-upon commitment period of the Kyoto Protocol coming to an end in 2012, it is important to understand the impacts of the Protocol so as to shed light on the design and implementation of a successor to the current system. This paper therefore complements the existing literature on climate change and international trade by providing empirical evidence for the effects of climate change policies on international merchandise trade. By assessing whether the Kyoto Protocol is associated with a shift in the patterns of international trade flows, the paper sheds light on the important industry relocation channel of potential carbon leakage.

There are three main lines of literature that are related to the current study. The first is the thriving literature on carbon accounting. Most of these studies employ input-output analysis to quantify CO_2 emissions embodied in international trade flows (see Minx et al., 2009 for an overview of such applications), similar to the literature on factor content of trade. Developed economies such as the E.U. and the U.S. tend to be net importers of embodied carbon, while emerging economies such as China and Russia are often net exporters (Peters & Hertwich, 2008; Atkinson, Hamilton, Ruta, & van der Mensbrugghe, 2010). This paper utilizes similar data on international trade, and the data on CO_2 emissions intensities are derived from an input-output analysis. However, rather than focusing on the overall carbon content of trade, it examines the patterns of trade in goods across disaggregated industries. An advantage of carrying out the analysis at a finer level than typical carbon accounting studies is that it limits issues related to sector aggregation stemming from within sector heterogeneity in trade exposure and emissions intensities as discussed in Wiedmann, Lenzen, Turner and Barrett (2007) and Su, Huang, Ang and Zhou (2010).

The second line of literature concerns the pollution haven hypothesis. These studies build on the intuition that everything else equal, countries or regions with weaker environmental regulations tend to have a comparative advantage in polluting industries and these places become pollution havens as they open up to trade. Early studies, mostly utilizing cross-sectional data across countries or industries, do not find significant evidence for the hypothesis (see Chua, 1999 for a survey), partly hampered by the fact that the industries with the largest abatement costs tend to be the least geographically mobile (Ederington, Levinson & Minier, 2005). Later analyses, taking advantage of newly available panel data and using more advanced econometric techniques, have found support for the hypothesis for new plant locations (List, Millimet, Fredriksson, & McHone, 2003), FDI (Keller & Levinson, 2002; Dean, Lovely & Wang, 2009) as well as trade flows (Levinson & Taylor, 2008; Broner, Bustos, & Carvalho, 2011). This paper draws on the empirical tradition in this literature and attempts identify the potential sources of comparative advantage in CO_2 emissions-intensive industries. The baseline estimation equations are particularly similar to the study by Broner et al. (2011) on comparative advantage in industries intensive in local air pollutants. Apart from the focus on a global bad in CO_2 emissions, this paper also differs in the following ways. While Broner et al. (2011) have relied mostly on a cross-sectional specification, I also exploit the panel structure of available trade data to analyze patterns of trade before and after significant developments in climate change policies. In addition, while they use a survey based measure on stringency of environmental regulation to proxy for cross-country differences in relative pollution costs, I use a direct measure based on actual climate change policies, namely the commitment to emissions targets under the Kyoto Protocol.

The last set of studies look at the economic impacts of existing and potential climate change policies, driven by carbon leakage or competitiveness concerns resulting from unilateral abatement policies like the Kyoto Protocol or the E.U. Emissions Trading System (ETS).[8] A myriad of papers have reported simulation results of various policy scenarios, based on computable general equilibrium (CGE) models or integrated assessment models (IAM) which combine the scientific and economic aspects of climate change (see Karp, 2010

[8]E.U. ETS is a cornerstone of the E.U.'s policy to combat climate change and its key tool for meeting its emissions target under the Kyoto Protocol. Launched in 2005, it was the world's first large-scale emissions trading scheme.

and Zhou, Kojima & Yano, 2010 for recent reviews). These models generally have strong parametric assumptions, while the parameters are not typically estimated using actual data. Therefore the results are very sensitive to assumptions of specific models and the reported measures of carbon leakage vary wildly.[9] Partial equilibrium models have also been used, primarily for studies of specific sectors, such as the cement or iron and steel industries under the E.U. ETS (Demailly & Quirion, 2006; 2008). Only a handful of studies have attempted to empirically assess the impacts of specific policies. A World Bank (2008) study concludes that both carbon taxes and energy efficiency standards have a negative effect on competitiveness for industries that are energy intensive or subject to higher energy efficiency standards. It also reports a gradual increase in the import-export ratio of energy intensive goods in developed countries, and a gradual decline in the ratio in some developing regions, suggesting potential leakage. Reinaud (2008), however, finds no evidence for carbon leakage in the aluminum sector as a result of the E.U. ETS. While industry-specific analyses offer insights on potential impacts of climate change policies, other studies have taken a broader perspective to assess economy-wide effects. Grunewald and Martínez-Zarzoso (2011) finds that an obligation from the Kyoto Protocol has a measurable reducing effect on a country's overall CO_2 emissions. Aichele and Felbermayr (2010) finds evidence that Kyoto commitments affect trade in embedded carbon and suggests substantial carbon leakage. Douglas and Nishioka (2009) pays special attention to the international differences in sectoral emissions intensities, and finds no evidence that developing countries specialize in emissions-intensive sectors. Using richer data, this paper adds to the empirical literature by analyzing the effect on the composition of industry trade flows. The findings echo those from the aforementioned studies in that climate change policies do appear to have an impact on production and trade, however, countries without quanti-

[9]The reported figures range from single digits to over 100, measured in terms of the increase in emissions in non-participating economies resulted directly from unilateral abatement policies as a percentage of mitigated emissions in the participating countries.

fied emissions targets under the Kyoto Protocol do not seem to specialize in emissions-intensive industries.

In sum, this paper contributes to the existing literature by empirically assessing the impacts of climate change policies on the patterns of international trade across industries using detailed trade and CO_2 emissions data. Specifically, I examine whether committing to a quantified emissions target under the Kyoto Protocol is associated with a shift in the patterns of trade in industries with high versus low emissions intensities. The study uses the U.S. imports data which cover a large number of developed and developing countries and the level of analysis is much more disaggregated than similar studies with the newly available U.S. industry emissions intensity data. I also take advantage of the panel data structure to examine patterns of trade before and after the adoption of the Kyoto Protocol.

3 Empirical Strategy and Estimation Equations

3.1 Cross-sectional Specification

In this section, I describe in detail my empirical strategy and the main estimation equations to assess the effectiveness of climate change policies and identify potential carbon leakage. I analyze the relationship between such policies and patterns of international trade in industries with varying levels of CO_2 emissions intensities. The empirical analysis is informed by recent developments in quantitative general equilibrium models of trade. Eaton and Kortum (2002) develops a multi-country model of international trade with a continuum of industries that captures the Ricardian forces of comparative advantage, based on technological differences, as well as geographical barriers. Their probabilistic formulation of technological heterogeneity allows a tractable framework for general equilibrium analysis and results in a gravity equation for bilateral trade flows. Chor (2010) extends the Eaton-Kortum model beyond aggregate trade volumes and incorporates both Ricardian and

Heckscher-Ohlin (H-O) forces, based on relative factor endowments, in order to quantify the importance of various sources of comparative advantage within a common framework. Chor's model explains cross-country patterns of specialization based on the intuition that industries vary in factor input requirements and institutional support needed for production, and countries differ in their abilities to meet these industry-specific requirements. Comparative advantage therefore arises from these country-industry matches. By unpacking the technological parameter in the Eaton-Kortum model, Chor derives the following estimation equation (equation (18) in Chor, 2010) to assess the various determinants of comparative advantage,

$$\ln(X_{ni}^k) = \sum_{f=1}^{F} \beta_f \left(\ln \frac{\omega_{if}}{\omega_{i0}} \right) s_f^k + \sum_{\{l,m\}} \beta_{lm} L_{il} M_m^k + \beta_d D_{ni} + \alpha_i + \alpha_{nk} + \upsilon_{ni}^k \quad (1)$$

where X_{ni}^k denotes the trade flow from exporter i to importer n in industry k, ω_{if} the price for factor f in country i, s_f^k the share of factor f in production for industry k, L_{il} an institutional measure l for country i, M_m^k the dependency of industry k on institution component m, D_{ni} the bilateral general distance variables, α's the fixed effects, β's the regression coefficients and υ the error terms. In this cross-sectional specification, log bilateral industry trade flows are regressed on the following determinants of comparative advantage: (i) H-O forces, through the interaction of exporter's relative factor prices, $\ln \frac{\omega_{if}}{\omega_{i0}}$, and industry factor shares, s_f^k; (ii) institutional forces, captured by the interaction between the exporter institutional measures, L_{il}, and industry dependency measures, M_m^k; (iii) bilateral distance variables, D_{ni}, that impose an iceberg cost on trade, including physical distance, linguistic ties, colonial links, border relationships, and trade agreements; (iv) an exporter fixed effect, α_i, which absorbs any exporters' country-specific characteristics that have common effects on trade flows across industries and importers; and (v) an importer-industry fixed effect, α_{nk}, which collects such factors as specific industry demand by an importing country or an industry specific tariff rate of an importer, provided it does not vary across exporters. This estimation equation embeds the empirical specification of recent studies on sources of comparative advantage ranging from factor endowments (Romalis, 2004) and energy abundance (Gerlagh & Mathys, 2011), to institutional sources such as financial development (Beck, 2003) and legal institutions (Levchenko, 2007; Nunn, 2007). Using this specification, Chor (2010) finds that factor endowments and legal institutions appear to have the largest influence on industry trade specialization. In the specification in this paper, I will control for the factor endowments in my estimation, since emissions intensities are more likely to be correlated with factor shares than dependency on legal institutions.

To use equation (1) for the analysis of comparative advantage in emissions-intensive industries, I can treat the stringency of climate change policies as an institutional measure and use CO_2 emissions intensities as the dependency score of each industry on a country's climate change institutions. Alternatively, I can model CO_2 emissions as a factor of production, a common practice in the theoretical literature on trade and the environment. I then view emissions intensity as analogous to factor shares and use the stringency of climate change policies to approximate for the relative emissions prices. Copeland and Taylor (2001) provides a particular functional form of emissions abatement technology so that emissions modeled as a joint output in production can be equivalently expressed as an input factor. Drawing on that work, Broner, et al. (2011) explicitly extends Chor's model to include pollution as an additional factor for production and derives an estimation equation to analyze comparative advantage in polluting industries. Adding to equation (1) the emissions related interaction and leaving out other institutional terms, I have,

$$\ln(X_{ni}^k) = \beta_E \left(\ln \frac{\tau_i}{\omega_{i0}}\right) s_E^k + \sum_{f=1}^{F} \beta_f \left(\ln \frac{\omega_{if}}{\omega_{i0}}\right) s_f^k + \beta_d D_{ni} + \alpha_i + \alpha_{nk} + \upsilon_{ni}^k \quad (2)$$

where τ_i is the price of emissions in country i, in the form of an emissions tax or implicitly embodied in the cost of energy use. The additional term is the interaction of the industry emissions share in production, s_E^k, and the relative price of emissions in the exporting country, $\ln \frac{\tau_i}{\omega_{i0}}$. As Copeland and Taylor

(2001) pointed out, their model does not allow "polluting to prosperity," i.e., there is an upper bound of emissions per physical unit of output. Only when τ_i is high enough will emissions prices factor into the firms' decisions, and induce active emissions abatement which can be viewed as substitution between emissions and other factors of production. In a world where emissions are not regulated anywhere, β_E is zero and equation (2) reduces to equation (1). When the emissions prices are high enough in a group of countries, β_E is expected to be negative, through both the direct channel of cost of production in countries with high enough emissions prices and the indirect general equilibrium production relocation effect that countries with non-binding emissions prices are also affected.

I estimate equation (2) in the current study using the stringency of climate change policies in a country, CP_i, to proxy for the relative emissions price, $\ln \frac{\tau_i}{\omega_{i0}}$. In particular, I use the indicator variable for Annex I status under the Kyoto Protocol. A number of previous studies have utilized the same measure as a proxy of the stringency of climate change policies (Aichele & Felbermayr, 2010; Yörük and Zaim, 2008). The underlying assumption is that there is a link between a country's Kyoto commitment and actual climate change policies that result in higher emissions prices. The Kyoto commitment is more of a signal of more stringent climate change policies rather than a direct policy measure by itself. This measure may be correlated with other country characteristics or institutional measures that may potentially affect trade patterns, some of which I will control for in robustness checks. Moreover, because it is a bivariate variable, only the average effect of Annex I membership to the Kyoto Protocol on the patterns of trade can be estimated with potential country heterogeneity remaining undisclosed. For the industry emissions share s_E^k, I will use the measure of CO_2 emissions intensity, i.e., the amount of CO_2 emitted per unit of production, which will be described in detail in the next section.

In this paper, I use U.S. imports data for empirical estimation. When estimating equation (2) with only one importer, all the bilateral distance variables $\beta_d D_{ni}$ will be absorbed into the exporter fixed effect α_i. Following the standard approach in the literature (Romalis, 2004), I use factor endowment ratios $\ln \frac{V_{if}}{V_{i0}}$ to proxy for factor price ratios $\ln \frac{\omega_{if}}{\omega_{i0}}$. Note that this will reverse the sign of β_E, since the two are inversely correlated. The main cross-sectional estimation equation is now

$$\ln(M_i^k) = \beta_E CP_i s_E^k + \sum_{f=1}^{F} \beta_f \left(\ln \frac{V_{if}}{V_{i0}} \right) s_f^k + \alpha_i + \alpha_k + \upsilon_{ni}^k \tag{3}$$

where log U.S. imports, $\ln(M_i^k)$, are regressed on the interaction of Annex I status, CP_i, and CO_2 emissions intensities, s_E^k, the factor interactions $\left(\ln \frac{V_{if}}{V_{i0}} \right) s_f^k$ and exporter and industry fixed effects α_i and α_k. Standard errors are two-way clustered by exporting country and industry for two considerations. First, because of data availability at the level of analysis, I do not include many institutional forces identified as determinants of comparative advantage in the recent literature. This will not be a serious problem for estimating the parameter of interest, β_E, as long as these forces are not correlated with the emissions interaction. However, the omitted unobserved variables may make error terms correlate for a given exporter or an industry. The other concern is of the type illustrated by Moulton (1990). Since the regression attempts to measure the effects on country-industry trade flows by country and industry characteristics, which are measured at a more aggregated level, even small levels of correlation of errors within countries or industries can cause OLS standard error to be seriously biased downward.

As mentioned before, using a binary policy measure in the regression assumes homogeneous responses in trade patterns to Kyoto commitment. However, there are substantial differences between the Annex I countries in many dimensions. One important observation is that the EIT countries have substantially lower emissions levels compared to the baseline of 1990 (or earlier years) when the Kyoto Protocol was adopted (see Table 1 for the change between the baseline and year 1998 levels), hence the quantified emissions targets specified in the Protocol may not be binding at all for these countries. Therefore it is likely that there is meaningful heterogeneity within the Annex

I countries in trade patterns. To explore whether this is the case, I estimate the following regression,

$$\ln(M_i^k) = \sum_{j=1}^{J} \beta_j I_j s_E^k + \sum_{f=1}^{F} \beta_f \left(\ln \frac{V_{if}}{V_{i0}} \right) s_f^k + \alpha_i + \alpha_k + \upsilon_{ni}^k \tag{4}$$

where the emissions interaction term, $CP_i s_E^k$, in equation (3) is replaced with a set of interactions of emissions intensity, s_E^k, and the series of indicator variables for each of the Annex I countries, I_j. I examine the estimated coefficient, β_j, for each country to check if there is an interesting pattern in heterogeneity within the Annex I group.

All the estimation equations specified above exploit the difference in the stringency of climate change policies between the Annex I and the non-Annex I countries to identify a differential pattern in industry trade flows. It is also informative to separately analyze the pattern of specialization with respect to industry emissions intensity for the two groups of countries. The last cross-sectional analysis I do is to estimate the following equation for the respective groups,

$$\ln(M_i^k) = \beta_E s_E^k + \sum_{f=1}^{F} \beta_{fs} s_f^k + \sum_{f=1}^{F} \beta_f \left(\ln \frac{V_{if}}{V_{i0}} \right) s_f^k + \alpha_i + \upsilon_{ni}^k \tag{5}$$

where log imports, $\ln(M_i^k)$, are regressed on emissions intensity, s_E^k, industry factor shares, s_f^k, and factor interactions, $\left(\ln \frac{V_{if}}{V_{i0}} \right) s_f^k$, with country fixed effects, α_i. Since there is no variation in Annex I status within the Annex I and the non-Annex I groups, the emissions interaction term, $CP_i s_E^k$, in previous equations reduces to emissions intensity s_E^k. Therefore industry fixed effects cannot be included while industry factor shares s_f^k are added in. Standard errors are two-way clustered by exporter and industry. Estimating equation (5) allows comparison between the Kyoto Protocol's direct effect on committed countries and the indirect effect on non-committed countries with respect to specialization in emissions-intensive industries. If the Kyoto-induced carbon leakage is strong enough and there is a composition effect of emissions-intensive sectors relocating to the non-Annex I countries, one would expect β_E to be negative for the Annex I countries and positive for the non-Annex I countries. In addition, this approach allows the coefficients on the H-O forces to differ for the two groups of countries, which is consistent with the theoretical model behind the estimation equations. If the prices of emissions in the non-Annex I countries are so small that emissions do not matter for firms' decisions, then the impact of other factor interactions will be more pronounced compared to countries with more stringent climate change policies.

3.2 Endogeneity

So far, I have described the strategy for a cross-sectional analysis using data for a particular year. One potential concern for such estimation is that of endogenous selection. Countries did not randomly become Annex I Parties to the UNFCCC and take on commitments under the Kyoto Protocol. First, it is conceivable that the countries that were already specializing in less emissions-intensive industries, for other reasons than more stringent climate change policies, self-selected to become Annex I Parties to the UNFCCC. If this is true, then despite statistical significance, the cross-sectional estimation cannot establish a valid relationship between climate change policies and patterns of trade. Second, since Annex I status is determined in 1992 with the adoption of the UNFCCC, years before the Kyoto Protocol, it is possible that the Annex I Parties had already implemented stringent climate change policies and their economy had shifted away from emissions-intensive production prior to signing and ratifying the Kyoto Protocol. In this scenario, commitments by the Annex I parties are a mere reflection of their existing stringent climate change policies rather than signifying further tightening. Nonetheless, the cross-sectional estimation can still identify the effects of climate change policies on patterns of trade, though it will not be evidence for Kyoto Protocol having any influence. To explore if any of these concerns are indeed the case, I examine data from years prior to and after the adoption of the Kyoto Protocol in the following three ways.

First, I pool the yearly cross-sectional data and carry out a regression using the full panel spanning the period of 1990 to 2010. I introduce two versions of the indicator variable for Annex I status, and run the following regression

$$\ln(M_{i,t}^k) = \beta_E^R CP_{i,t}^R s_E^k + \beta_E CP_i s_E^k + \sum_{f=1}^{F} \beta_f \left(\ln \frac{V_{if}}{V_{i0}} \right) s_f^k + \alpha_{i,t} + \alpha_{k,t} + \upsilon_{i,t}^k \quad (6)$$

where trade flows $M_{i,t}^k$ are now also indexed by year t, and the fixed effects are now specified as exporter-year effect, $\alpha_{i,t}$, and industry-year effect, $\alpha_{k,t}$, to allow for changes of the country and industry specific factors over time. Standard errors are still two-way clustered by exporter and industry, now allowing for potential autocorrelation of the error term in addition to the issues for the cross-sectional specification. CP_i is the same time-invariant indicator for Annex I status, assigned 1 if country i has committed to a quantified emissions target under the Kyoto Protocol. $CP_{i,t}^R$ is a time-varying indicator, only positive for years after the country ratified the Kyoto Protocol. It has been used by other studies in panel specifications (Aichele & Felbermayr, 2010; Grunewald & Martínez-Zarzoso, 2011). By including both versions of interaction terms as explanatory variables, the estimation can provide evidence on the extent to which there were preexisting patterns of specialization in emissions-intensive industries before the signing of the Kyoto Protocol, captured by β_E, and the extent to which there were changes in the pattern following the ratification of the Protocol, captured by β_E^R. If β_E is not significantly different from zero, one can rule out both types of concerns discussed earlier. A significant β_E implies that there were significant differences in patterns of specialization in emissions-intensive industries even before the Kyoto Protocol, though it cannot distinguish the source of these differences. On the other hand, if β_E^R is significantly below zero, one can infer that Kyoto commitments did have an impact on top of any preexisting patterns. This way, I can identify if an Annex I Party's ratification of the Kyoto Protocol indeed institutes more stringent climate change policies that significantly affects patterns of trade.

A second approach is to estimate equation (3) for every year from 1990 to 2010. I then check whether the time-varying β_E is significantly different from zero for years before the signing of the of the Kyoto Protocol or it is only the case after the Protocol entered into force. If it is indeed the case that β_E is not significantly different from zero prior to Kyoto but only moves into the negative territory as countries ratified the Protocol, then there is evidence that Kyoto commitments mattered for patterns of specialization. Compared with the single regression of equation (6) using the full panel, the approach with a series of regressions is more flexible to the extent that β_E and the coefficients on the factor interactions, β_f's, are all allowed to differ over time, which is consistent with the idea that the same Annex I status signifies varying level of stringency of the climate change policy at different stages with respect to the Kyoto Protocol. On the other hand, it does not directly utilize information on the variation in the year that each Annex I Party ratified the Kyoto Protocol. To provide evidence on the effect of the Kyoto Protocol on industry specialization for the Annex I and the non-Annex I countries separately, I analyze time-varying coefficients for equation (5) in a similar fashion.

The last approach I adopt is to estimate a long-difference specification. I analyze the difference of log industry trade flows before and after the Kyoto Protocol. The previous specifications explore the potential change in the effect of Annex I status on the patterns of trade over time, while this approach attempts to assess the differential impact of the Kyoto Protocol on the growth rates of trade flows for high and low emissions-intensive industries. By first differencing the log trade flows between two years before and after the Kyoto Protocol entered into force and regressing them on the interaction of Annex I status and emissions intensity, I test if there is a significant impact of the change in climate change policy on the change in trade patterns. This method controls for all time-invariant factors that affect the levels of trade flows. I obtain the following specification by first differencing equation (3) (or equation

(6)),

$$\Delta \ln(M_i^k) = \beta_E CP_i s_E^k + \sum_{f=1}^{F} \Delta\beta_f \left(\ln \frac{V_{if}}{V_{i0}} \right) s_f^k + \Delta\alpha_i + \Delta\alpha_k + \Delta\upsilon_{ni}^k \qquad (7)$$

where $\Delta \ln(M_i^k)$ is the log difference, or the growth rate, of imports from country i in industry k, CP_i (or equivalently ΔCP_i^R) is the same measure of Annex I status but now represents a change in climate change policy, and the fixed effects $\Delta\alpha_i$ and $\Delta\alpha_k$ now control for country or industry specific factors that result in heterogeneous average growth rates of country or industry trade flows, such as a country signing a trade agreement with the U.S. or an increase in U.S. demand for a particular industry. Considering the relatively short time period of several years, I have assumed that other country and industry specific characteristics, including industry emissions intensity, s_E^k, factor shares, s_f^k's, and relative factor endowments, $\left(\ln \frac{V_{if}}{V_{i0}}\right)$, have not changed over the period. Hence the factor interaction terms will disappear if β_f's remain unchanged. One complication is that before Kyoto, the cost of emissions may not be internalized in private firms' optimization process, and therefore the coefficient for other factor interaction terms may indeed be different from those after Kyoto. For robustness, I report estimation results with and without the factor interaction terms. The estimated $\Delta\beta_f$'s represents change in the coefficients in the baseline cross-sectional specification. A statistically significantly negative β_E estimate implies that Kyoto commitments had an impact on the evolution of trade patterns in the immediate aftermath of the introduction of the Protocol. It is consistent with the idea that the Kyoto Protocol fostered more stringent climate change policies in the Annex I countries and the patterns of international trade have changed in the several years after the adoption of the Protocol as firms adjust to the more stringent policies. To explore whether there is any evidence of a preexisting trend in the Annex I countries toward specializing in less emissions-intensive products prior to the Kyoto Protocol, I conduct a similar regression on first-differenced log trade flows between two years before the Kyoto Protocol entered into force.

4 Data

4.1 CO_2 Emissions Intensities

In this section, I describe the data used in the analysis. I focus on the data on CO_2 emissions intensities for disaggregated industries. Due to data availability, industry level CO_2 emissions intensities are created based on only U.S. data from a recent report by the Economics and Statistics Administration of the U.S. Department of Commerce (ESA, 2010). The report analyzes energy-related CO_2 emissions and intensities for all Iliad industries,[10] government and households in the U.S. for the years of 1998, 2002 and 2006. The Iliad model is a detailed input-output model with 360 input-output sectors based on the 2002 North American Industry Classification System (NAICS). Out of these sectors, 255 correspond to industries in agriculture, mining and manufacturing, with exposure to merchandise trade. The data provide the most detailed account of CO_2 emissions intensities available to my knowledge. These disaggregated industries will be the level of analysis in this paper.

The dataset on emissions intensities is derived from detailed data on energy use by industries. The majority of the energy-related emissions are attributable to heat and power. Direct input of energy to production, such as natural gas used in producing fertilizer, and process emissions for a small number of industries, namely cement and lime, are also considered. The intensities are measured in the amount of CO_2 emissions produced per unit value of gross output, and are reported in both the direct emissions by an industry and the total emissions embodied in the final goods of an industry taking into account emissions embodied in domestic and imported intermediates.[11] For manufacturing industries, I am able to adjust such measures by the gross output to value added ratios of individual industries to obtain a value added based measure. Unfortunately, data on value added for agricultural and mining industries are only available at a more aggregated level.

[10] Iliad stands for *Interindustry Large-scale Integrated And Dynamic model of the U.S.*.

[11] The ESA (2010) report assumes that the CO_2 emissions intensities of imported goods and services are the same as domestically produced ones.

It is important to choose an appropriate measure of emissions intensity for use in the estimation. The two candidates both seem viable: the intensity of total emissions embodied in the final goods of an industry, $s^k_{E,T}$, measured in tons of total embodied CO_2 emissions per \$1000 of gross output in constant year 2000 dollars; and the intensity of direct emissions of an industry, $s^k_{E,D}$, measured in tons of direct CO_2 emissions by the industry per \$1000 of value added in constant year 2000 dollars. (Henceforth, I suppress the units of the emissions intensities for brevity.) The theoretical model on which the estimation equations are based does not offer direct guidance for the choice as the model does not include intermediate inputs. The output-based measure, $s^k_{E,T}$, is available for all industries and takes into account the entire production cycle of the final output of an industry. Ignoring imported inputs, $s^k_{E,T}$, probably provides a more comprehensive measure of an industry's dependence on climate change policies, assuming the emissions charges to upstream industries are transferred through the cost of intermediate inputs. However, the cost of the embedded emissions may not be fully passed through and imported inputs may be important for certain industries. Furthermore $s^k_{E,T}$ may be less accurately measured as estimating embedded emissions involve more complicated analysis than that for direct emissions. On the other hand, the value added-based measure, $s^k_{E,D}$, seems to be more in line with the theoretical model if intermediate inputs are ignored. Emissions intensities are used to proxy for the share of the emissions-associated charges in production cost, s^k_E, based on a Cobb-Douglas value added production function. Provided that the emissions price τ^k is high enough to matter in the firms' decision making process, s^k_E can be expressed as $s^k_E = \frac{\tau^k E^k}{Y^k}$, where E^k is the amount of emissions and Y^k is the value added for an industry. In the context of a country with lax or no emissions regulations, like the U.S., the emissions price is zero or non-binding. However, it is assumed that the emissions are nonetheless supplied perfectly elastically at a positive shadow price, which ensures that the countries cannot "pollute to prosperity." If all industries are subject to a uniform (shadow) price τ for CO_2 emissions in the U.S. and τ is high enough for all industries, then $s^k_{E,D} = \frac{E^k}{Y^k}$ will be a rescaled measure for s^k_E. In reality, this is unlikely the case as emissions-associated costs are small and vary across industries, in addition to the issue of intermediate inputs. Hence each measure has its advantages and shortcomings. I will therefore use both when applicable. Thankfully, for manufacturing industries for which both measures are available, the correlation between the output- and the value added-based measures is very high. As Table 3 shows, it is at about 0.98 for the intensities and 0.85 for the ranking of intensities. Therefore, the choice of an emissions intensity measure is unlikely to alter estimation results in a meaningful way.

I treat emissions intensity as a time- and country-invariant characteristic of each industry and use the average of the measures over 1998, 2002 and 2006 for all of the analysis. For this approach to be valid, the crucial assumption is that the relative emissions intensities do not vary over time or across countries. Over the period for which data are available, the measured emissions intensities are on a general decreasing trend and the average emissions intensity of the U.S. economy went down by about 20%. Therefore, if I were to analyze the evolution of total CO_2 emissions over time, I could not overlook the fact that technological advances are the main reason for emissions reduction in the U.S., compared to industry relocation or composition changes (Levinson, 2009; Wang, 2014). However, since the main objective of this paper is to explore the potential effect of variation in climate change policies on the patterns of trade in relation to the relative emissions intensities across industries, I only need these relative intensities to remain stable over time, i.e., an emissions-intensive industry before the Kyoto Protocol kept being emissions intensive relative to other industries in the economy afterwards. As shown in Table 4, this is indeed the case for the U.S. as the correlation between the measures from the three years (panel (1) and (2), over 0.96) as well as the ranking of these measures (panels (3) and (4), over 0.88) are all very high. Therefore it seems safe to use an average measure of emissions intensities as a time-invariant measure for analysis on data from all years.

Similar to previous studies, since I only have detailed data on emissions for U.S. industries, I also need to assume that the relative intensities are the same across economies, i.e., a country can be clean and have a less emissions-intensive economy than others, but an industry that is relatively emissions intensive elsewhere still entails more emissions relative to the cleaner industries in that country. I recognize that there are substantial differences in emissions intensities across countries, due to technological access, energy sources and within industry composition. However, if the advances in energy efficiency, abatement technology and clean energy options are not biased toward some particular industries, but apply in general to all industries, then it is conceivable that the relative emissions intensities will be similar across countries. This may indeed be true if most of the developments in the CO_2 emissions abatement technologies are applied in the energy sector, as all other industries consume the produced electricity or fuel and all benefit from the technological advances. To verify that the relative intensities are stable across countries, I analyze available country specific data with more aggregated industries. Since data on emissions intensities are not readily available, I use data on industry energy use and output from the Global Trade Analysis Project (GTAP) to calculate energy intensities for different countries and check the correlations to see if there is significant variation across countries. Since most of the CO_2 emissions are attributable to energy use (ESA, 2010), results on energy intensities should carry over to emissions intensities. Table 5 presents the correlation coefficients between the energy intensity measures for 42 sectors in food and manufacturing in the GTAP model for 12 countries in year 1997. The selected countries are the G8+5 group (excluding South Africa for which data are not separately available), i.e., the major economies of the world. It is clear that industry energy intensities are indeed highly correlated across countries. Except for pairings involving Germany (in the 0.8 to 0.9 range), all the correlations are well above 0.9. Based on these findings, I use the emissions intensity measures derived from U.S. data for analysis of all countries.

For a first look at the emissions intensity data, Table 2 lists the 20 most and the 20 least CO_2 emissions-intensive industries, ranked by $s^k_{E,T}$. The most emissions-intensive industries fall into three categories: those with substantial process emissions in production, namely lime and cement; the ones that use large amount of fossil fuels as feedstock for production, such as fertilizer and industrial gas; and the energy-intensive industries including several mining industries and metal products. The list is broadly consistent with those identified as industries that may be affected the most by climate change regulations in a report by the U.S. Environmental Protection Agency (EPA) (2009) and studies elsewhere (Grubb et al., 2009). The least emissions-intensive industries tend to be high-tech industries that are capital and skill intensive. They usually produce high value added products so that energy or emissions cost will be a small fraction of the value of output. High value added is also probably the reason why tobacco products claim the crown of the cleanest good in terms of CO_2 emissions. Another observation from Table 2 is that a few most emissions-intensive industries have intensities well above the rest, while the least emissions-intensive industries tend to have very similar levels of intensities. The 20th least intensive industry has an intensity that is only 0.13 higher than the very least intensive industry. On the other hand, the gap in intensities between the 3rd and the 20th most intensive industries is 4.3, more than 30 times larger. Indeed, the distribution of industry CO_2 emissions intensities is highly skewed to the right. Figure 3 shows the distribution of the log of the emissions intensities for both the output and value added based measures. Even in logs, the distribution clearly has a fat right tail. Since the log function is a concave transformation, the distribution for the original measures is even more skewed to the right. A potential concern resulting from this feature of the distribution of the intensities data is that the estimation results could be driven by a few outliers, i.e., the most emissions-intensive industries. I will address the issue by checking whether excluding outliers significantly alters the estimation results.

4.2 Climate Change Policies

Another variable of central interest in the analysis is the measure for stringency of climate change policies. I use a country's Annex I status to the UNFCCC and its commitment to a quantified GHG emissions target under the Kyoto Protocol as an indicator of a country's climate change policies. As discussed in Section 3, I use two versions of the measure. The time-invariant Annex I indicator, CP_i, assigns 1 to country i if it is currently (as of October, 2011) an Annex I Party with a quantified target under the Kyoto Protocol. The time-varying indicator, $CP^R_{i,t}$, assigns 1 to an Annex I Party starting from the year after it ratified the Kyoto Protocol. There are other ways of assigning the time varying Annex I status with respect to the Kyoto Protocol: according to when a country signs the Protocol (before ratification), when the Protocol actually went into force for the country (the later of February 2005 or 90 days after ratification), or adopting a uniform break with a year between the adoption of the Protocol (1997) and when it went into effect (2005). All yield similar results for our estimation. As for the non-Annex I economies, I do not distinguish if they are Parties to the UNFCCC or the Kyoto Protocol, as both treaties have almost universal coverage for UN members (with the United States being the only notable exception).

4.3 Other variables

The dependent variables used in the estimation are log trade flows or long-differenced log trade flows. For the main analyses, I use U.S. import data in Harmonized System (HS) 10-digits from the U.S. Census Bureau. The data for years 1990 to 2005 are obtained from Schott (2008), and those for years 2006 to 2010 are from data disks published by the Census Bureau (2007-2011). Data are then aggregated to the Iliad industry level, using HS to NAICS concordances provided by the Census Bureau and Pierce and Schott (2009), and NAICS to Iliad concordances from the Interindustry Forecasting Project at the University of Maryland (Inforum). 238 Iliad industries record positive trade flows in the data, out of which 215 are manufacturing industries. The panel of trade flows is unbalanced. There are many zeros or missing data for possible exporter-industry pairs, so the estimation results must be interpreted as conditional on positive trade flows.

Data on factor endowments, factor intensities of production and other country characteristics are from standard sources. Relative capital endowment is proxied by the capital-labor ratio from the Extended Penn World Tables (EPWT) (Marquetti, 2011), averaged for years 1990 to 2009. Relative human capital abundance is proxied by average years of education from Barro & Lee (2001). I use the data from 2000, which is the latest available. Capital and skill shares are calculated from value added, total payroll and production worker payroll data. The shares are averaged over 1990 to 2009. Data from 1990 to 2005 are from NBER CES manufacturing industry database (Becker & Gray, 2009); data from 2006 to 2009 are obtained from the Annual Survey of Manufactures (ASM) and 2007 Economic Census and Surveys by the U.S. Census Bureau (2007, 2009-2010, 2008). Since the focus of the paper is on the cross-sectional pattern of trade and the time series variation over this short interval of time is likely to be small relative to cross-sectional variation across countries, I treat these country and industry specific measures as time invariant.

I also obtain income per capita, CO_2 emissions per capita and CO_2 intensity of GDP for each year from the EPWT (Marquetti, 2011). The survey based measure of stringency of a country's environmental regulations is from the Global Competitiveness Report (World Economic Forum (WEF), 2007).

5 Empirical Results

5.1 Baseline Results

In this section, I report results based on estimation of the cross-sectional specifications of equations (3)-(5). I first present here as baseline result a pure cross-sectional analysis of the data on U.S. imports in 2007 based on equation (3). I choose 2007 because it is the last year before the collapse of trade in the Great Recession, while late enough for the economies to adjust for policy changes brought about by the Kyoto Protocol. Regressions based on data from other years in mid to late 2000s yield similar results. The estimated coefficient for the interaction $CP_i s_E^k$ is negative and statistically significant, suggesting that the Annex I countries export less to the U.S. in emissions-intensive industries relative to the non-Annex I countries, which is consistent with the hypothesis that climate change policies are important for comparative advantage. In particular, it implies that for an industry with an emissions intensity half a standard deviation above the mean, such as the glass containers industry, an Annex I country will export on average just over 20% less to the U.S. than an non-Annex I country, controlling for general effects of country characteristics on all industries and common effects of industry specific factors on all countries This effect is similar whether I consider all industries (column (1) of Table 6) or only manufacturing industries (column (2)), or whether I use the output based measure (columns (1) and (2)) or the value added based measure (column (3)) of emissions intensity.

CO_2 emissions-intensive industries are mostly energy-intensive industries, which are also likely capital intensive and less skill intensive. the Annex I countries are high income countries, generally with higher capital labor ratio as well as better education than the non-Annex I countries. Therefore one would worry that the results presented above are only a reflection of the factor endowments as determinants of comparative advantage. Regression results with controls for interactions of country factor endowment ratios and industry factor shares are reported in column (4) of Table 6. Adding controls for capital and skill interactions does reduce the magnitude of the estimated coefficient on the emissions interaction, however, it remains significant at five percent level, which suggests that the effect found for the interaction of emissions intensity and Annex I status is not merely capturing other classical determinants of comparative advantage. In addition, the magnitude of the effect of the emissions intensity interaction is similar to the factor intensity interactions. The estimated coefficient implies that an Annex I country would export about 29% less to the U.S. than a non-Annex I country in an industry with an emissions intensity one standard deviation above the mean. On the other hand, a country with one standard deviation above the mean in average schooling would export 38% more, than a country with a mean level of education, in an industry with a skill share one standard deviation above the mean. The interaction of capital-labor ratio and capital shares does not seem to have a significant effect.

5.2 Robustness

To ensure that the findings of the cross-sectional estimation are valid, I carry out some robustness analysis. Including country and industry fixed effects in the estimation already addresses a number of concerns, such as neutral differences in technology levels across countries that have common effect on exports across industries, or differences in the relative volume of U.S. imports across industries. One potential remaining problem in the estimation of equation (3) is that environmental regulation is partially determined by other country characteristics. In particular, it is possible that richer citizens care more about potential damages of climate change and demand more stringent climate change policies. Alternatively, it is possible that countries with higher emissions per capita feel more responsible to address climate change related issues. This leads to a positive correlation between climate change regulation and those country characteristics. If emissions intensity is also correlated with other industry characteristics, the omission of these other determinants of comparative advantage might bias the estimated effect of climate change policy on comparative advantage. To address this concern, I estimate equation (3) including controls for interactions of emissions intensity with emissions per capita, emissions intensity of the overall economy and income per capita. The results are reported in columns (2)-(4) and (6)-(8) of Table 7. The coefficient on the original interaction does not change a lot in magnitude but becomes less significant, yet none of the added interactions are significant, suggesting difficulty in isolating the effect associated with Kyoto commitment from others. Part of the reason could be the moderate correlation between these country characteristics and Annex I status. The Annex I countries are precisely the high income industrialized countries. Another possible issue could be nonlinearities similar to the environmental Kuznets curves (Grossman & Krueger, 1993; 1995; Dinda, 2004). A country could be specializing in less emissions-intensive industries because it actively mitigates emissions as a high-income country or because it does not have the capacity for more emissions-intensive industries as a low-income country. It's possible such forces made the model less suitable when including such interactions, and large standard errors emerge. Nonetheless, since the main objective is to identify possible effects of climate change policies rather than the Kyoto Protocol per se, the results presented for the cross-sectional regressions remain meaningful as long as the emissions intensity is not highly correlated with other industry characteristics through which the omitted country characteristics have a differential effect on high and low emissions-intensive industries.

One potential issue related to variables used in the analysis is that of the highly skewed distribution of industry CO_2 emissions intensities, as described in section 4. There are no industries with intensities more than one standard deviation below the mean using either measure, while there are some industries with intensities more than two standard deviations above the mean, such as the lime, cement and fertilizer industries. Since these handful of industries have emissions intensities that are far from the rest, one potential concern is that the pattern of trade presented above may be driven solely by the small number of industries. To provide evidence on whether this is the case, I replicate the analysis on equation (3) excluding data from the industries with an emissions intensity more than 1.5 standard deviations above the mean based on the output based measure.[12] This translates into leaving out the 7 most emissions-intensive industries listed in Table 2. The results are presented in Table 8. All the results are qualitatively the same as those with full data (see Table 6). In fact, the estimated coefficients on the emissions interaction terms are substantially larger in magnitude compared to the baseline estimation. Therefore it seems that rather than driving the relationship between climate change policies and trade patterns, the most emissions-intensive indus-

[12] Iglewicz and Hoaglin (1993) recommend using the modified Z-score $M_i = 0.6745(x_i - \tilde{x})/\text{MAD}$ with MAD denoting the median absolute deviation and $\tilde{x}$ denoting the median, and label modified Z-scores with an absolute value of greater than 3.5 as potential outliers. Industries with an intensity measure $s^k_{E,T}$ 1.5 standard deviation above the mean have a modified Z-score of more than 4 based on log intensities.

tries seem to be lagging in response. This echoes with previous findings that the most emissions-intensive industries often receive protection from national climate change policies in the form of subsidies or exceptions, and the actual effect on such industries are much smaller compared to other unprotected industries (World Bank, 2008).

Table 9 presents the results of the baseline estimation using an alternative measure of the stringency of a country's climate change regulations. A survey based measure of stringency of environmental policy is used in the place of the indicator variable for Kyoto commitment. It is not surprising that a similar pattern is found in that a country with more stringent environmental regulations tends to export less to the U.S. in more CO_2 emissions-intensive industries. After all climate change policies are part of environmental regulations. Indeed, Annex I status is highly correlated with the stringency of a country's environmental regulations, at about 0.8. In addition, the survey measure provides much finer detail than the binary indicator for Annex I status. The advantage of using the Kyoto commitment as the variable for the estimation, however, is that it is directly related to an actual policy commitment that specifically addresses the issue of climate change, allowing the results to have a more meaningful interpretation.

Another concern arises regarding the particular composition of the Annex I and the non-Annex I groups. Countries were not randomly assigned to be Annex I parties and there are substantial differences between the two groups. In particular, the Annex I countries are industrialized countries which tend to have higher income per capita and a more developed manufacturing sector, both of which are closely related to international trade flows. Therefore, it is not easy to find the perfect comparison group among the non-Annex I countries. To partly address this concern, I present results using different comparison groups in Table 10. The reported pattern of specialization remains the same when excluding the observations on low income countries, low and lower-middle income countries, or low and middle income countries. In addition, it is noted that including or excluding any particular country, such as China or Germany, does not alter the reported results.

Lastly, I report estimation results using an alternative set of data. Since the previously reported results are based on U.S. imports data only, one may question the generality of the findings. I conduct the same analysis using data from the Industrial Demand-Supply Balance (IDSB) database from United Nations Industrial Development Organization (UNIDO). As Table 11 shows, the results exhibit a similar pattern whether industrial output or exports to the rest of the world are used, suggesting the reported relationship between Kyoto commitment and trade patterns is not solely driven by using U.S. data and offering some direct evidence that climate change policy is related to industry composition.

5.3 Within-Annex I Heterogeneity

As discussed in section 3, a concern of using Annex I status, a binary variable, as the measure for climate change policies is that only an average effect is identified. It is informative to investigate if there are substantial variations in the effects within the Annex I group. To explore the potential differences, I regress log imports on interactions of emissions intensity with indicator variables for each of the Annex I countries, as specified in equation (4). I plot the estimated coefficients on the interaction term of emissions intensity with individual Annex I country indicators against a crude measure of the restrictiveness of their Kyoto commitment in figure 4. The restrictiveness is proxied by the difference between the level of a country's GHG emissions in 1998 and its quantified target level specified in the Kyoto Protocol, as a percentage of the country's emissions in the baseline year.[13] A positive number means that the country is emitting more in 1998 than its target level in the commitment period of 2008-2012 and needs to actively reduce emissions for compliance; the higher the number the more restrictive is the country's commitment. A weakness of this measure is that it does not take into account

[13] This restrictiveness measure is calculated by taking the difference between the change from baseline to 1998 (column Δ(90-98)) and the emissions reduction target (column Target) reported in table 1. The year 1998 is chosen since the Kyoto Protocol was adopted in December of 1997 and countries were deciding whether to sign the Protocol in 1998. Using other years in late 1990s or early 2000s does not alter the main feature of the plot.

the heterogeneity in expected growth rates among the countries. With a same (positive or not very negative) score, a country expecting to grow at a higher rate into the commitment period will face a tougher challenge of meeting the emissions target compared to one with a slower growth rate. Nonetheless, it is a convenient measure that offers interesting insights.

Figure 4 shows a clear correlation between the restrictiveness of a country's Kyoto commitment and its patterns of specialization. Countries whose commitment actually entails active reduction of emissions (those on the right half of the graph) tend to specialize in less emissions-intensive industries (in the bottom half of the graph) relative to non-Annex I countries in 2007, hence the concentration in the lower right quadrant. On the other hand, Russia, Belarus, Ukraine and a few others (in the upper left quadrant) have a significantly positive coefficient on the emissions interaction term, suggesting that they actually tend to specialize in emissions-intensive industries relative to an average non-Annex I country. Not surprisingly, these are the EIT countries with plenty of room to spare based on their commitments under the Kyoto Protocol. With their economies in drastic transition in the 1990s, these countries have a much lower emissions level compared to the base years around 1990 (see figure 2 and Table 1). Therefore, there is not much pressure for them in meeting the commitment in the 2008-2012 period and consequently little incentive to ramp up climate change regulations. The substantial within-Annex I heterogeneity found in this analysis suggest that the actual restrictiveness needs to be considered when assessing climate change policies. In the case of the Kyoto Protocol, the impact on EIT and non-EIT countries can be very different.

5.4 Comparison between Country Groups

The analyses above have provided strong evidence that stringent climate change policies signified by commitment under the Kyoto Protocol is associated with exporting relatively less in CO_2 emissions-intensive industries. As discussed in section 3, in addition to exploiting the difference between the

Annex I and the non-Annex I countries, it is also informative to separately analyze the pattern of specialization with respect to industry emissions intensity for the two groups. Since the previous analysis has identified substantial heterogeneity within the Annex I countries, particularly between the EIT and non-EIT countries, I will estimate equation (5) for three groups of countries: Annex I non-EIT, Annex I EIT and non-Annex I countries. Results are reported in Table 12 for all industries and manufacturing industries respectively. The patterns found are very similar whether or not the interaction terms of factor shares and relative factor endowments are included. The only statistically significant coefficient of interest is the one on the emissions intensity for the Annex I non-EIT countries. On average, these countries export about 25% less to the U.S. in an industry compared to another that has an emissions intensity one standard deviation lower. The fact that those countries with restrictive Kyoto commitments do tend to specialize in less emissions-intensive industries suggests that the Kyoto Protocol is indeed associated with more stringent climate change policies with discernible effects on economic activities in countries with meaningful commitment to reduce emissions. On the other hand, the coefficients for emissions intensity for the Annex I EIT and the non-Annex I countries are not statistically significant from zero. Therefore there is insufficient evidence that countries with less stringent climate change policies are specializing in emissions-intensive industries. Nonetheless it is the difference across the groups of countries that matters in assessing the effects of the policy, as specified in the baseline regression.

6 Endogeneity

As discussed in section 3, one must be cautious in interpreting the cross-sectional results presented in the previous section. This is because causality may run from trade flows to climate change policy. Countries may have chosen to become Annex I Parties to the UNFCCC and commit to quantified targets under the Kyoto Protocol when they were already specializing in less emissions-intensive industries. To address this concern, I exploit the time dimension of the data on trade flows and present three sets of results that provide evidence against this potential alternative explanation.

6.1 Panel Specification

As explained in section 3, I pool the cross sectional data for each year and use the full panel for an estimation of equation (6). I characterize the change in the regression coefficient of the interaction term of emissions intensity and Annex I status before and after a country ratified the Kyoto Protocol, by including two sets of interaction variables: a time-invariant one, based on a country's commitment under the Protocol, and the other time-varying one, only positive for years after a country's ratification. The regression includes industry-year fixed effects, which capture any factor that affects export in all countries in the same way in a given industry year, as well as country-year fixed effects, which capture the factors that influence exports in all industries in the same manner for a given country year.

Results are shown in Table 13. In columns (1) and (3), only the time-varying interaction term is included in the panel regression, implicitly assuming that there was nothing special about an Annex I country prior to ratifying the Kyoto Protocol, with respect to specialization in (less) emissions-intensive industries. The significantly negative coefficient is of comparable magnitude to the coefficients found in the cross-sectional regression with data from 2007, suggesting that the results of the cross-sectional regression presented in section 5 are representative of the period after most Annex I countries' ratification of the Kyoto Protocol. In columns (2) and (4), both the time-varying and the time-invariant interactions are included. The coefficient on the time-varying term is still highly significant and is about a little less than half of the magnitude of that as a single regressor. The significant coefficient represents a change in patterns of the Annex I countries' specialization relative to the non-Annex I countries after the Kyoto Protocol. It is consistent with the idea that ratifying the Protocol does signal a more stringent climate change policy and the resulting higher cost of emissions makes the Annex I countries export less than before in CO_2 emissions-intensive industries. On the other hand, the coefficient on the time-invariant term is of larger magnitude than that on the time-varying term, but is only significant at the 10level, lending only weak support to the hypothesis that the Annex I countries had been exporting relatively less in emissions-intensive industries prior to ratifying the Kyoto Protocol. When the factor interactions are included (column (5)), the coefficient on the time-varying term is smaller in magnitude but remains significant at five percent level, while that on the time-invariant term becomes insignificant. This suggest that at the specialization pattern of the Annex I countries prior to Kyoto can be largely explained by differences in relative factor endowment, particularly skill abundance, while the change in the trade patterns after Kyoto likely comes from sources other than relative factor endowment, for instance, the more stringent climate change policies. In sum, the evidence provided by the full panel estimation suggests that the cross-sectional results in section 5 indeed represent an effect that can be associated with the Kyoto Protocol and controlling for factor interactions likely takes care of the weak pre-Kyoto specialization patterns.

6.2 Time-varying Coefficients

A closely related approach to address the selection issue is to estimate equation (3) for each year from 1990 to 2010 and check whether the patterns of trade with respect to varying emissions intensities have changed before and after the Kyoto Protocol. As discussed in section 3, this approach is more general than the full panel specification to the extent that it allows the coefficient on emissions interactions to vary flexibly over time, enabling a closer look for possible pre-trends and the evolution in the aftermath of the Kyoto Protocol. Figure 5 presents the series of the estimated coefficients on the emissions interaction term along with 95underlying regressions include factor interactions in addition to exporter and industry fixed effects. Standard errors are two-way clustered by country and industry.

The series seems to be rather flat and not different from zero until the year 2000, after which there is a clear downward trend, coinciding with the period that the Annex I countries ratified the Kyoto Protocol. Eventually, it becomes statistically different from zero. This is consistent with the previous findings that there is little evidence that the Annex I countries were exporting less emissions-intensive goods before the Kyoto Protocol, and the policy change signified by the ratification of the Protocol does have a statistically significant effect. Namely, the pattern that an Annex I country exports less in emissions-intensive industries relative to an non-Annex I country emerged after the adoption of the Kyoto Protocol in late 1997 and eventually becomes statistically significant as it approaches the commitment period of the Protocol. The fact that the coefficient is close to zero and not moving much prior to Kyoto provides evidence that there was not a preexisting trend for the Annex I countries to shift toward cleaner exports. Thus there is no evidence that endogenous selection into Annex i status is driving the results.

I further analyze the two sets of countries separately, estimating equation (5) for the Annex I and the non-Annex I countries separately. This allows me to analyze the evolution of the trade patterns of the two groups separately. The series of the coefficients on emissions intensity are presented in figure 6. It is clear that although the coefficient for the Annex I countries is generally below zero and that for the non-Annex I countries above zero, they are not significantly different from each other until later in the period. Starting in the late 1990s, concurrent with the adoption of the Kyoto Protocol, there seems to be a diverging trend. Most of the increasing differences between the two groups are attributed to the decreasing trend of the coefficient for the Annex I Parties. It suggests that the more stringent climate change policies indeed mainly affect economic activities in countries that adopt them. There seems to be little evidence that the non-Annex I countries are moving toward specializing in more emissions-intensive industries, corroborating similar findings by Douglas and Nishioka (2009). This is an interesting observation since it suggests the general equilibrium relocation of production does not seem to have happened. Therefore the dreaded carbon leakage may not be as serious as some have feared, at least not through a composition channel. Since the data used are U.S. imports, this could be explained by either the U.S. domestic production moving toward more emissions-intensive industries or the U.S. demand moving toward less emissions-intensive industries. It warrants further analysis to see if the general equilibrium effect is indeed lacking in more comprehensive data. To summarize, the analysis on time-varying coefficients for both equations (3) and (5) confirms the findings in the panel specification and suggest that endogenous selection is unlikely a serious problem for the cross-sectional analysis in section 5.

6.3 Long Difference Specification

Another way to examine the impact of the Kyoto Protocol in changing export patterns is to estimate equation (7), with the specification in long differences. As discussed in section 3, the estimation is based on the intuition that the ratification of Kyoto Protocol constitutes a policy change for the Annex I countries. The fixed effects in the regression now control for the average growth rate of industry trade flows for each exporter and each industry. In reality it takes time for the real economy to respond to policy changes, therefore I exploit the changes in trade flows before and after the adoption (ratification) of the Kyoto Protocol to see if taking on a quantified emissions target under the Kyoto Protocol as an Annex I Party mattered for the patterns of trade. I look at changes between 1992 and 1999 and between 2000 and 2007. The reason for choosing 1999/2000 as the breaking point is that most countries signed the Protocol in 1998 or 1999 but did not ratify it until the early 2000s. In addition, the Protocol did not enter into force until 16 February 2005. Choosing other reasonable years yields similar results. Table 14 shows that the effect of Annex I status of an exporter on the growth of U.S. imports is significant for the Kyoto period, suggesting that committing to emissions abatement under the Protocol does make a country shift away from exporting emissions-intensive goods relative to non-committed economies. On the other hand, no effect is found for the pre-Kyoto period, again providing strong evidence that there had not been a pre-Kyoto trend for the Annex I countries to specialize in less emissions-intensive industries.

Exploiting the time dimension of the trade data, I am able to address the potential selection issue with a number of approaches. I find no evidence that the Annex I countries exported less in emissions-intensive industries prior to the adoption of the Kyoto Protocol. Rather, there is a statistically significant decline in their export in such industries following the ratification of the Protocol. This pattern is consistent with an impact of the Kyoto Protocol on patterns of specialization across industries and on overall emissions through a change in the composition of exports and production.

7 Conclusion

In this paper I empirically assess the impact of climate change policies on economic activities using detailed data on industry CO_2 emissions intensities and U.S. imports from 1990 to 2010. Using estimation strategies informed by recent developments in quantitative general equilibrium models of international trade, I find that climate change regulations are an important determinant of comparative advantage in emissions-intensive industries. In particular, the Annex I countries which commit to quantified emissions targets under the Kyoto Protocol export less in CO_2 emissions-intensive industries. The pattern is particularly strong for countries that have restrictive emissions targets which call for active mitigation in compliance. The result is robust to a variety of specification checks out of concern for the particular variables used in the estimation. The magnitude of the effect is comparable to that of traditional determinants of comparative advantage, namely relative factor endowments. Exploiting the panel structure of the data, I show that the pattern found for years after the Kyoto Protocol went into effect (in 2005) was absent in years prior to or immediately after the adoption of the Protocol (in 1997). It gradually emerged as countries signed and ratified the Protocol in the early 2000s. This result suggests that more stringent climate change policies can affect industry composition in countries that administer such policies. On the other hand, there is insufficient evidence that countries not committed to reduce carbon emissions are becoming more specialized in emissions-intensive industries. Policy makers should take into account such effects on industry structure when evaluating climate change policies, particularly the unilateral mitigation schemes or the NDCs under the Paris Agreement. With a truly global mechanism, the effects on industry structure and patterns of trade could be quite different from those found here.

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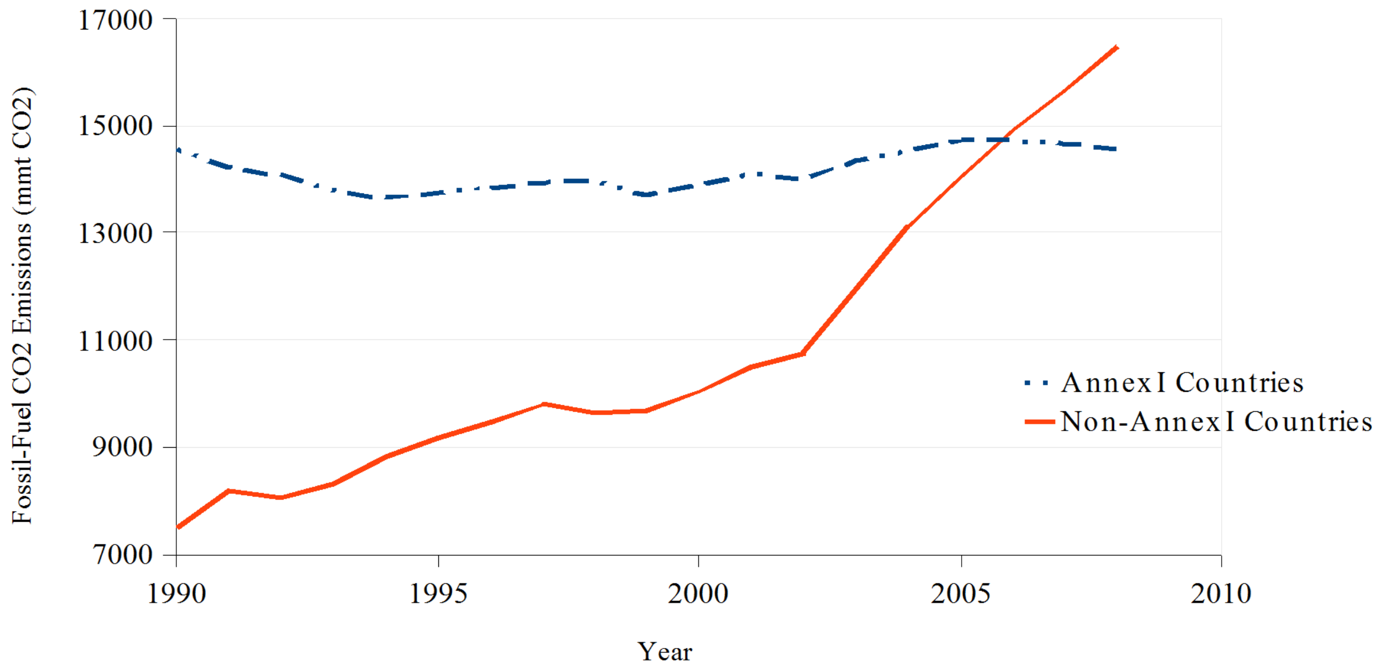

Figure 1: Fossil-Fuel CO_2 Emissions From Annex I and non-Annex I Countries

Data source: Boden, Marland, & Andres, 2011.

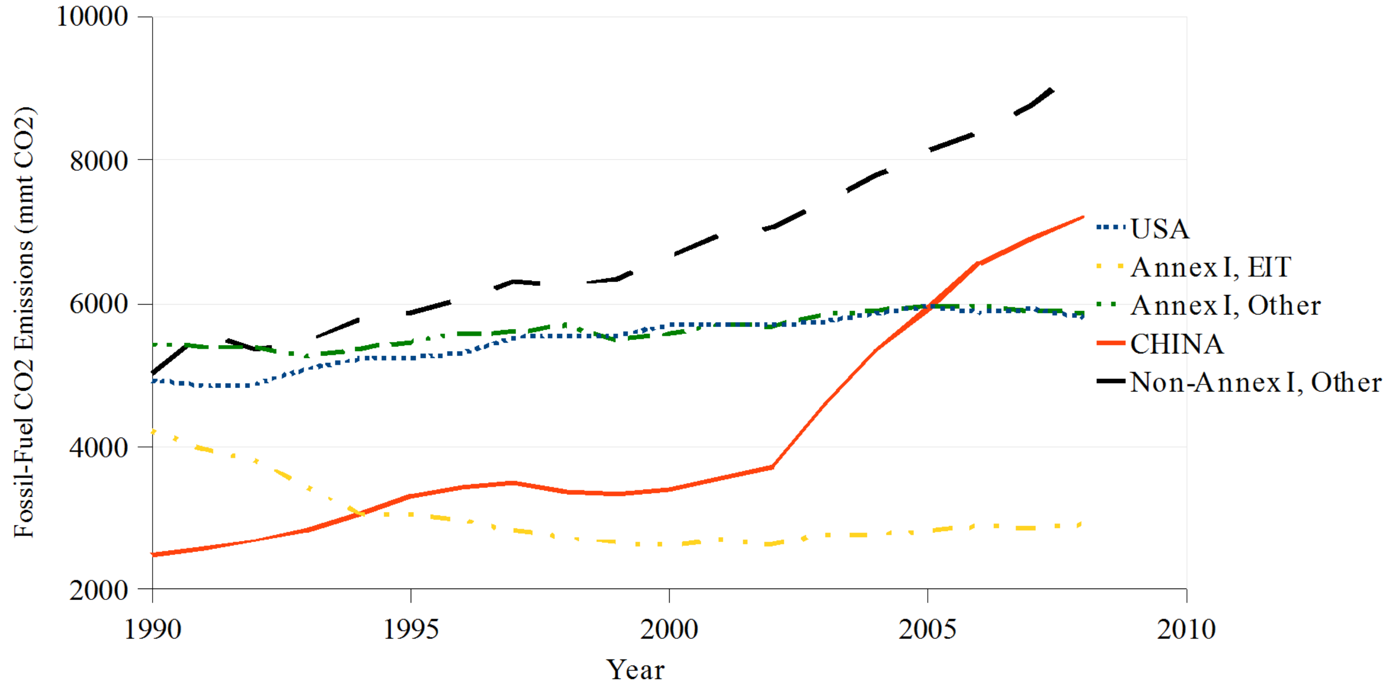

Figure 2: Fossil-Fuel CO_2 Emissions from Selected Country Groups

Data source: Boden, Marland, & Andres, 2011.

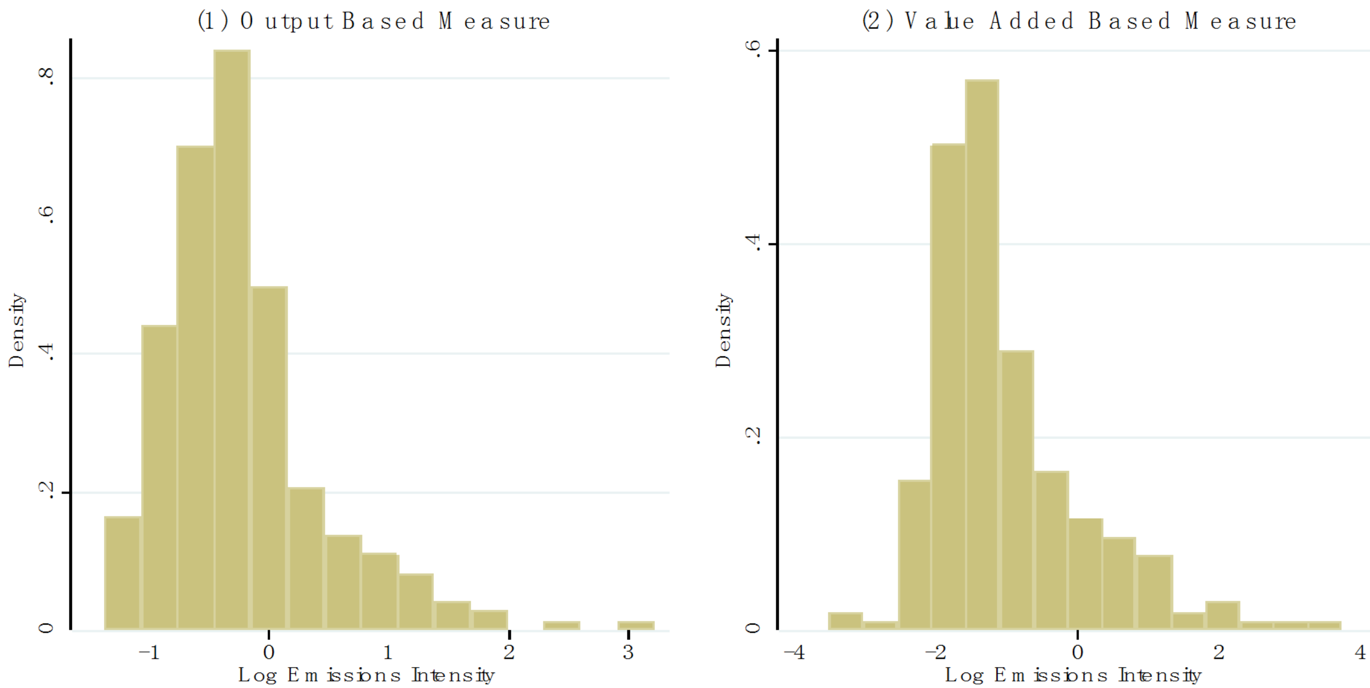

Figure 3: Distribution of CO_2 Emissions Intensities

Note: Histograms shown are for log of the emissions intensities.
Data source: ESA, 2010; Becker & Gray, 2009.

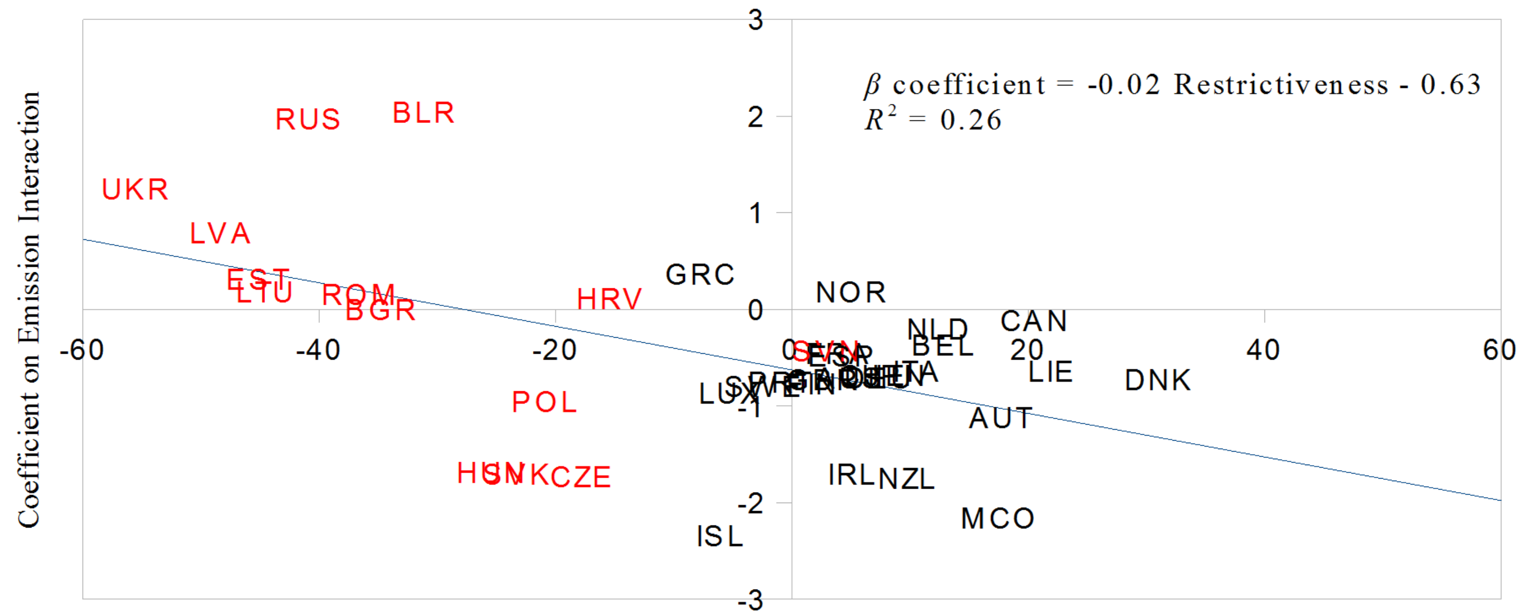

Figure 4: Heterogeneity and Restrictiveness of Kyoto Commitment

Note: Each data point is an Annex I country. Regression coefficients are obtained from estimating equation (4) using data for manufacturing industries in 2007. Factor interactions are not included as data are not available for all Annex I countries. Restrictiveness is measured as the difference between 1998 emissions level and the target level for 2008-2012 as a percentage of baseline emission level (1990).
Red country codes denote EIT countries. Equation for trend line is given at top right.

Data source: UNFCCC and author's calculation.

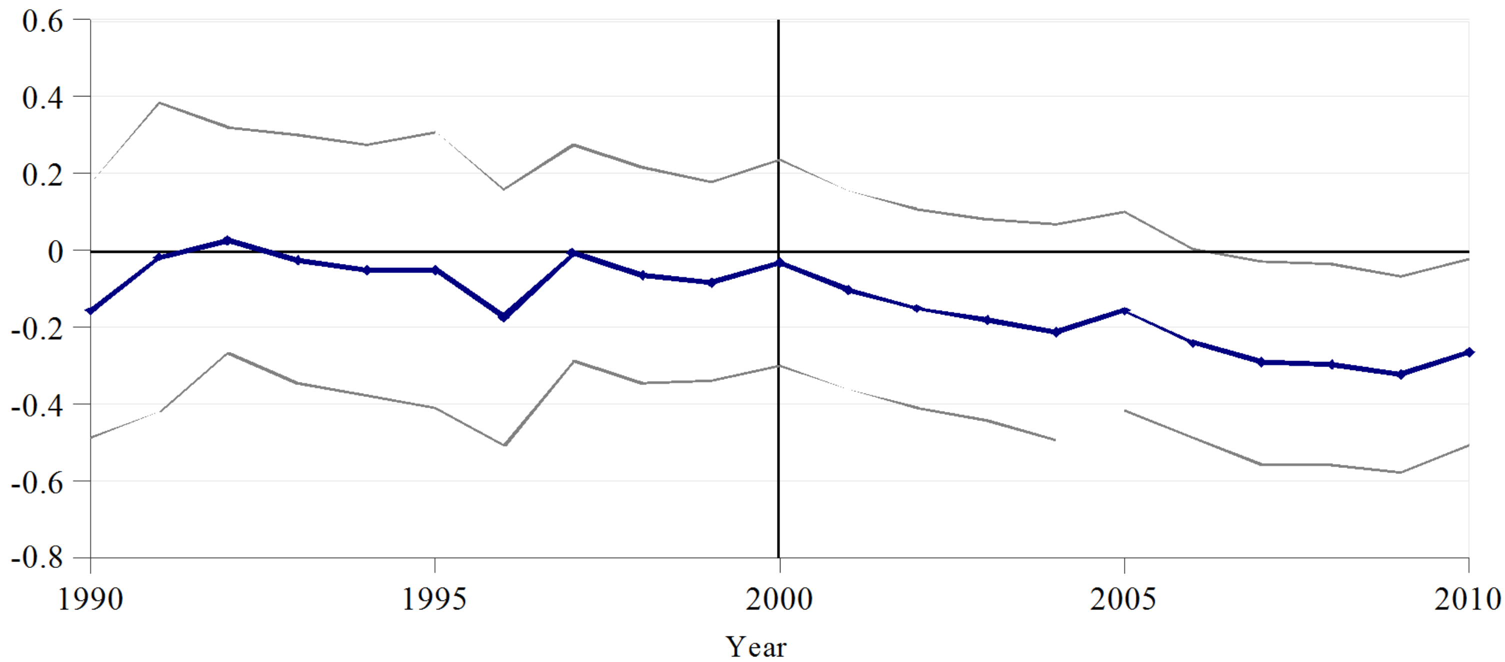

Figure 5: Time-varying Coefficient on Emissions Intensity × Annex I Status

Note: Coefficients are obtained from estimating equation (3) using data on manufacturing industries for each year. Factor interactions and exporter and industry fixed effects are included. Confidence intervals are based on standard errors two-way clustered by exporter and industry.

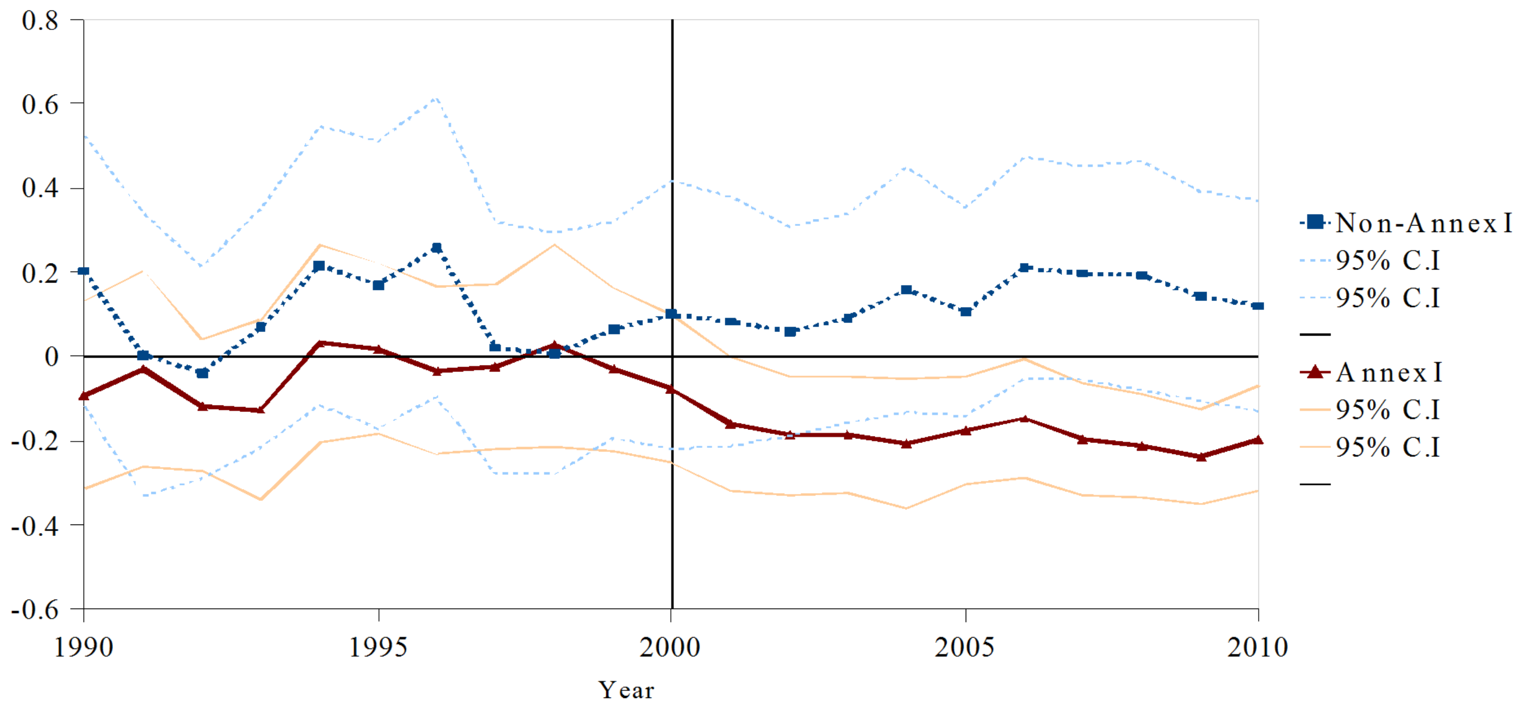

Figure 6: Time-varying Coefficient on Emission Intensity by Annex I Status

Note: Coefficients are obtained from estimating equation (5) using data on manufacturing industries for each year. Factor shares, factor interactions and exporter fixed effects are included. Confidence intervals are based on standard errors two-way clustered by exporter and industry.

Table 1: Annex I Parties to the UNFCCC and Commitments under the Kyoto Protocol

Party	Date of Ratification	Target[a] Ax.B	Target[a] Art.4[b]	Base Level[c]	Δ 90-98[d]	Party	Date of Ratification	Target Ax.B[a]	Base Level[c]	Δ 90-98[d]
EU (15).[b]	May 2002	-8	-8		-1.7	Croatia*	May 2007	-5		-20.3
Austria	May 2002	-8	-13	0.4	4.7	Czech*	Nov 2001	-8	1.2	-25.7
Belgium	May 2002	-8	-7.5	0.8	5.4	Estonia*	Oct 2002	-8	0.3	-53.0
Denmark	May 2002	-8	-21	0.4	10.2	Hungary*[a]	Aug 2002	-6	0.5	-31.4
Finland	May 2002	-8	0	0.4	1.8	Iceland	May 2002	10	0.0	4.1
France	May 2002	-8	0	2.7	4.1	Japan	Jun 2002	-6	8.5	2.8
Germany	May 2002	-8	-21	7.4	-13.6	Latvia*	Jul 2002	-8	0.2	-56.1
Ireland	May 2002	-8	13	0.2	18.2	Liechtenstein	Dec 2004	-8	0.0	14.2
Italy	May 2002	-8	-6.5	3.1	4.2	Lithuania*	Jan 2003	-8		-52.4
Greece	May 2002	-8	25	0.6	17.3	Monaco	Feb 2006	-8	0.0	9.7
Luxembourg	May 2002	-8	-28	0.1	-33.2	New Zealand	Dec 2002	0	0.2	9.9
Netherlands	May 2002	-8	-6	1.2	6.5	Norway	May 2002	1	0.3	6.2
Portugal	May 2002	-8	27	0.3	26.1	Poland*	May 2002	-6	3.0	-26.7
Spain	May 2002	-8	15	1.9	19.3	Romania*	Mar 2001	-8	1.2	-44.4
Sweden	May 2002	-8	4	0.4	1.8	Russia*	Nov 2004	0	17.4	-40.7
U.K.	May 2002	-8	-12.5	4.3	-9.7	Slovakia*	May 2002	-8	0.4	-31.0
Australia	Dec 2007	8		2.1	13.0	Slovenia*	Aug 2002	-8		-5.0
Belarus*#	Aug 2005	-8			-39.0	Switzerland	Jul 2003	-8	0.3	-1.0
Bulgaria*	Aug 2002	-8		0.6	-42.7	Ukraine*	Apr 2004	0		-55.5
Canada	Dec 2002	-6		3.3	14.7	U.S^		-7	36.1	10.8

[a] This column reports the emissions target, as a percentage change from the base-year levels, specified in Annex B to the Kyoto Protocol. [b] 15 member States of the E.U. at the time of adoption of the Kyoto Protocol agreed to meet their targets jointly in accordance with Article 4. The column "Art.4" reports their respective targets. [c] This column reports a country's base-year emissions levels as a percentage of total emissions from all Annex I countries. [d] This column reports changes in CO_2 -equivalent GHG emissions without land use, land-use change and forestry from the base year to 1998 as a percentage of the base-year emissions. * A Party undergoing the process of transition to a market economy. An Annex I EIT party may choose a base year other than 1990. # The amendment to include Belarus in Annex B to the Kyoto Protocol (with a quantified emissions reduction commitment of eight percent) has not yet entered into force. ^The U.S. is not a Party to the Kyoto Protocol. *Note*: Malta and Turkey are currently Annex I Parties to the UNFCCC, however, they do not have commitments under the Kyoto Protocol. Data source: UNFCCC.

Table 2: The Most and the Least CO_2 Emissions Intensive Industries

Most Emissions-Intensive Industries	Intensities		Least Emissions-Intensive Industries	Intensities	
	$s^k_{E,T}$	$s^k_{E,D}$		$s^k_{E,T}$	$s^k_{E,D}$
Lime	24.9	41.7	Tobacco products	.26	.04
Cement	12.1	17.4	Support activities for printing	.29	.13
Fertilizers	6.6	10.4	Propulsion units, parts for space vehicles, guided missiles	.29	.20
Iron ore mining	6.0	-	Computer storage devices	.29	.16
Gold, silver, and other metal ore mining	4.9	-	Electricity and signal testing instruments	.31	.13
Other nonmetallic mineral mining	4.6	-	Other ordnance and accessories	.31	.13
Primary aluminum production	4.6	7.8	Guided missiles and space vehicles	.31	.22
Industrial gas	3.6	5.6	Telephone apparatus	.32	.06
Sand, gravel, clay and refractory mining	3.6	-	Surgical and medical instruments	.32	.09
Wet corn milling	3.4	6.9	Electronic computers	.33	.03
Aluminum products	3.2	1.8	Search, detection, and navigation instruments	.33	.12
Primary ferrous metal products	3.2	4.3	Distilleries	.33	.15
Ready-mix concrete	3.1	.63	Packaging machinery	.35	.15
Copper, nickel, lead, and zinc mining	2.9	-	Metal cutting and forming machine tool	.35	.12
Primary copper	2.8	2.0	Analytical laboratory instruments	.35	.11
Other basic inorganic chemicals	2.8	3.5	Broadcast and wireless communications equipment	.36	.13
Petrochemicals	2.8	3.7	Ophthalmic goods	.37	.13
Other basic organic chemicals	2.5	3.7	Musical instruments	.37	.19
Plastics material and resins	2.4	3.0	Pharmaceuticals and medicines	.39	.12
Stone mining and quarrying	2.3	-	Forestry and logging	.39	-

Note: $s^k_{E,T}$ measures total emissions per output, $s^k_{E,T}$ measures direct emissions per value added. Units are in metric tons of CO_2 per $1000 in constant year 2000 dollars. Industries are ranked by the output based emissions intensity $s^k_{E,T}$. The value added based measure $s^k_{E,D}$ is only available for manufacturing industries.

Data source: Output based CO_2 emissions intensities from ESA, 2010; output and value added from Becker & Gray, 2009.

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Table 3: Correlation Between Output and Value Added Based Measures

	1998	2002	2006	Average
Correlation, $s^k_{E,T}$, $s^k_{E,D}$	0.9774	0.9789	0.9792	0.9804
Correlation, ranks	0.8424	0.8519	0.8850	0.8667

Note: $s^k_{E,T}$ measures total emissions per output, $s^k_{E,T}$ measures direct emissions per value added. Units are in metric tons of CO_2 per $1000 in constant year 2000 dollars.

Data source: ESA, 2010; Becker & Gray, 2009.

Table 4: Correlations of CO_2 Emissions Intensities Across Time

	1998	2002	2006	Average	1998	2002	2006	Average
	(1) $s^k_{E,T}$				(2) $s^k_{E,D}$			
1998	1				1			
2002	0.9846	1			0.9915	1		
2006	0.9655	0.9640	1		0.9859	0.9916	1	
Average	0.9928	0.9927	0.9856	1	0.9960	0.9981	0.9955	1
	(3) Rank $s^k_{E,T}$				(4) Rank $s^k_{E,D}$			
1998	1				1			
2002	0.9189	1			0.9127	1		
2006	0.8865	0.9331	1		0.8851	0.9287	1	
Average	0.9687	0.9745	0.9608	1	0.9643	0.9714	0.9598	1

Note: $s^k_{E,T}$ measures total emissions per output, $s^k_{E,T}$ measures direct emissions per value added. Units are in metric tons of CO_2 per $1000 in constant year 2000 dollars.

Data source: ESA, 2010; Becker & Gray, 2009.

Table 5: Correlations of Energy Intensities Across Countries

	G8								+5[a]			
	CAN	FRA	DEU	ITA	JPN	RUS	GBR	USA	BRA	CHN	IND	MEX
Canada	1											
France	.98	1										
Germany	.87	.86	1									
Italy	.98	.99	.88	1								
Japan	.98	.98	.90	.99	1							
Russia	.96	.95	.83	.96	.95	1						
UK	.99	.98	.87	.99	.98	.95	1					
USA	.96	.96	.90	.97	.97	.93	.95	1				
Brazil	.99	.99	.88	.99	.99	.96	.99	.96	1			
China	.92	.96	.80	.92	.92	.92	.91	.91	.93	1		
India	.98	.95	.83	.97	.95	.94	.98	.92	.97	.91	1	
Mexico	.99	.98	.88	.99	.99	.97	.99	.97	.99	.93	.98	1

[a] South Africa is not included because data is not available for it as a separate country.

Note: Correlations reported for energy intensity measures for 42 food and manufacturing industries in the GTAP model for year 1997.

Data source: GTAP 5.4 Data Base.

Table 6: Climate Policy and Comparative Advantage: Baseline Estimation

Dependent variable:	All Industries	Manufacturing		
log imports	(1)	(2)	(3)	(4)
emissions intensity	-.455**	-.418**	-.462**	-.291**
× Annex I status	(.192)	(.168)	(.187)	(.140)
capital intensity				.029
× capital-labor ratio				(.096)
skill intensity				.394***
× year of schooling				(.105)
exporter fixed effect	Yes	Yes	Yes	Yes
industry fixed effect	Yes	Yes	Yes	Yes
intensity measure	$s_{E,T}^k$	$s_{E,T}^k$	$s_{E,D}^k$	$s_{E,D}^k$
R^2	.607	.640	.640	.631
# observations	18587	17230	17230	13667
# exporters	226	225	225	116

Note: Dependent variable is the log of U.S. imports in 2007. $s_{E,T}^k$ is the output based measure and $s_{E,T}^k$ is the value added based measure. Observations are exporter by industry for 2007. Standard errors two-way clustered by exporter and industry are in brackets. *** indicates significance at 0.01 level, ** at 0.05 level, * at 0.1 level.

Table 7: Robustness Check: Country Characteristics

Dependent variable: log imports	All Industries (1)	(2)	(3)	(4)	Manufacturing Industries (5)	(6)	(7)	(8)
emissions intensity								
× Annex I status	-.455**	-.521**	-.349*	-.325	-.291**	-.419**	-.188	-.248
	(.192)	(.223)	(.198)	(.212)	(.140)	(.189)	(.140)	(.203)
× emissions per capita		.149				.272		
		(.244)				(.281)		
× emissions per GDP			.287				.266	
			(.188)				(.207)	
× income per capita				-.149				-.052
				(.183)				(.189)
factor interactions	No	No	No	No	Yes	Yes	Yes	Yes
exporter fixed effect	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
industry fixed effect	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
R^2	.607	.596	.597	.596	.631	.632	.632	.631
# observations	18587	17359	17359	17367	13667	13659	13659	13667
# exporters	226	172	172	173	116	115	115	116

Note: Dependent variable is the log of U.S. imports in 2007. Observations are exporter by industry for 2007. Standard errors two-way clustered by exporter and industry are in brackets. *** indicates significance at 0.01 level, ** at 0.05 level, * at 0.1 level.

Table 8: Robustness Check: Excluding Outliers in CO_2 Emissions Intensities

Dependent variable:	All Industries	Manufacturing		
log imports	(1)	(2)	(3)	(4)
emissions intensity	-.723**	-.893**	-.939***	-.584*
× Annex I status	(.345)	(.374)	(.353)	(.353)
capital intensity				.037
× capital-labor ratio				(.059)
skill intensity				.386***
× year of schooling				(.086)
exporter fixed effect	Yes	Yes	Yes	Yes
industry fixed effect	Yes	Yes	Yes	Yes
intensity measure	$s^k_{E,T}$	$s^k_{E,T}$	$s^k_{E,D}$	$s^k_{E,D}$
R^2	.619	.648	.648	.639
# observations	18268	17045	17045	13559
# exporters	226	225	225	116

Note: Dependent variable is the log of U.S. imports in 2007. $s^k_{E,T}$ is the output based measure and $s^k_{E,T}$ is the value added based measure. Observations are exporter by industry for 2007. Observations in the 7 most emissions-intensive industries are excluded. Standard errors two-way clustered by exporter and industry are in brackets. *** indicates significance at 0.01 level, ** at 0.05 level, * at 0.1 level.

Table 9: Robustness Check: Using Survey Measure on Env. Regulation

Dependent variable:	All Industries	Manufacturing		
log imports	(1)	(2)	(3)	(4)
emissions intensity	-.351***	-.340***	-.368***	-.238**
× env. regulation	(.127)	(.129)	(.141)	(.104)
capital intensity				.116
× capital abundance				(.108)
skill intensity				.506***
× skill abundance				(.112)
exporter fixed effect	Yes	Yes	Yes	Yes
industry fixed effect	Yes	Yes	Yes	Yes
intensity measure	$s_{E,T}^k$	$s_{E,T}^k$	$s_{E,D}^k$	$s_{E,D}^k$
R^2	.590	.622	.622	.624
# observations	15917	14788	14788	13062
# exporters	127	127	127	98

Note: Dependent variable is the log of U.S. imports in 2007. $s_{E,T}^k$ is the output based measure and $s_{E,T}^k$ is the value added based measure. Observations are exporter by industry for 2007. Standard errors two-way clustered by exporter and industry are in brackets. *** indicates significance at 0.01 level, ** at 0.05 level, * at 0.1 level.

Table 10: Robustness Check: Varying Comparison Country Groups

	Excl. low income countries		Excl. low and lower mid. income		Excl. low and middle income	
Dependent variable: log imports	(1)	(2)	(3)	(4)	(5)	(6)
emissions intensity	-.474**	-.275**	-.513**	-.295**	-.647**	-.408
× Annex I status	(.190)	(.132)	(.205)	(.134)	(.301)	(.372)
capital intensity		.132		.082		.050
× capital abundance		(.111)		(.154)		(.205)
skill intensity		.645***		.685***		.531***
× skill abundance		(.116)		(.140)		(.190)
exporter fixed effect	Yes	Yes	Yes	Yes	Yes	Yes
industry fixed effect	Yes	Yes	Yes	Yes	Yes	Yes
R^2	.593	.618	.609	.624	.646	.649
# observations	16805	12751	13424	10463	8112	6508
# exporters	164	93	111	66	59	38

Note: Dependent variable is the log of U.S. imports in 2007. Observations are exporter by industry for 2007. Standard errors two-way clustered by exporter and industry are in brackets. *** indicates significance at 0.01 level, ** at 0.05 level, * at 0.1 level.

Table 11: Robustness Check: ISDB Data

Dependent variable:	Industrial Output		Export to ROW	
log output/export	(1)	(2)	(3)	(4)
emissions intensity	-.251***	-.137**	-.161***	-.143**
× Annex I status	(.069)	(.066)	(.052)	(.044)
capital intensity		.080		.076
× capital abundance		(.077)		(.083)
skill intensity		.149		.272***
× skill abundance		(.112)		(.094)
country fixed effect	Yes	Yes	Yes	Yes
industry fixed effect	Yes	Yes	Yes	Yes
R^2	.828	.811	.786	.776
# observations	4983	3934	7598	6218
# countries	58	45	82	65

Note: Dependent variable is the log of industrial output or export to the rest of world in 2007. Observations are country by industry for 2007. Standard errors two-way clustered by country and industry are in brackets. *** indicates significance at 0.01 level, ** at 0.05 level, * at 0.1 level.

Table 12: Export Patterns by Country Groups

	All Industries			Manufacturing		
	Annex I		Non-	Annex I		Non-
Dependent variable:	non-EIT	EIT	Annex I	non-EIT	EIT	Annex I
log imports	(1)	(2)	(3)	(1)	(2)	(3)
emissions intensity	-.285***	.493	.153	-.256**	.373	.198
× Annex I status	(.103)	(.497)	(.207)	(.126)	(.426)	(.259)
capital intensity				.294	-.153	.068
× capital-labor ratio				(.248)	(.210)	(.083)
skill intensity				.543**	.012	.242**
× year of schooling				(.219)	(.393)	(.103)
factor intensities	Yes	Yes	Yes	Yes	Yes	Yes
exporter fixed effect	Yes	Yes	Yes	Yes	Yes	Yes
R^2	.442	.148	.503	.408	.160	.479
# observations	4279	1914	10587	4463	1522	7682
# exporters	26	13	186	23	10	83

Note: Dependent variable is the log of U.S. imports in 2007. Observations are exporter by industry for 2007. Standard errors two-way clustered by exporter and industry are in brackets. *** indicates significance at 0.01 level, ** at 0.05 level, * at 0.1 level.

Table 13: Kyoto Ratification and Comparative Advantage

Dependent variable: log imports	All industries (1)	All industries (2)	Manufacturing (3)	Manufacturing (4)	Manufacturing (5)
emissions intensity	-.455***	-.193***	-.438***	-.189***	-.138**
	(.122)	(.071)	(.125)	(.069)	(.062)
emissions intensity		-.275*		-.260*	-.108
× Annex I status		(.142)		(.142)	(.139)
capital share					.007
× capital endowment					(.057)
skill share					.457***
× skill endowment					(.092)
exporter-year fixed effect	Yes	Yes	Yes	Yes	Yes
industry-year fixed effect	Yes	Yes	Yes	Yes	Yes
R^2	.576	.578	.611	.611	.606
# observations	341160	341160	313576	313576	255103
# exporters	238	238	238	238	118

Note: Dependent variable is the log of yearly U.S. imports from 1990 to 2010. Observations are exporter by industry by year. Standard errors two-way clustered by exporter and industry are in brackets. *** indicates significance at 0.01 level, ** at 0.05 level, * at 0.1 level.

Table 14: Changes in Trade Flows

Dependent variable: diff. log imports	2000-2007 (1)	2000-2007 (2)	1992-1999 (3)	1992-1999 (4)
emissions intensity	-.167**	-.221**	-.028	-.015
× Annex-I Status	(.069)	(.094)	(.065)	(.078)
capital intensity		.058**		.120***
× capital-labor ratio		(.028)		(.037)
skill intensity		-.019		.158***
× year of schooling		(.038)		(.055)
exporter fixed effect	Yes	Yes	Yes	Yes
industry fixed effect	Yes	Yes	Yes	Yes
R^2	.141	.156	.156	.164
# observations	14126	11295	11208	9169
# exporters	210	116	198	109

Note: Dependent variable is the difference of log of U.S. imports between the specified years. Observations are exporter by industry for each period. Standard errors two-way clustered by exporter and industry are in brackets. *** indicates significance at 0.01 level, ** at 0.05 level, * at 0.1 level.