The Kyoto Protocol and Patterns of International Trade

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Abstract

This paper analyzes the effects of climate change policy on international trade flows. Data on CO_2 emission intensities and US imports from 1990 to 2010 are used to test whether being an Annex I party to the Kyoto Protocol has an effect on a country's export patterns. The panel structure allows dealing with possible endogenous selection of countries into the Protocol. The findings confirm the commonly held but rarely empirically documented view that a country committed to reduce emissions exports less in CO_2 emission intensive industries. Moreover this effect is quantitatively important and comparable to that of the traditional sources of comparative advantage, such as factor endowments.

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I. Introduction

Climate change is one of the greatest challenges of our time. Deep cuts in global greenhouse gas (GHG) emissions are required to hold the increase in global average temperature below 2 degrees Celsius above per-industrial levels. Since the emissions are a global public bad, efficient mitigation efforts must entail international cooperation. However, because countries are in different stages of development and therefore have different priorities in national policies and varying responsibilities based on historical emission inventories, international cooperation in the form of a global cap or universal tax on emissions is hard to achieve. Unilateral emission abatement commitments in the form of the Kyoto Protocol suffer from free rider problems. Policy makers are concerned about "carbon leakage," i.e., emissions reduced by committed countries are offset by corresponding increase in non-committed countries; and they worry about the potential negative effect on the competitiveness of domestic companies in the emission intensive industries. On the other hand, there is also skepticism that the Protocol can be effective in reducing emissions, due to its lack of a strong punishment mechanism.

In this paper I analyze whether the Kyoto Protocol has had an effect on the organization of economic activities, particularly the patterns of international trade. I test whether a country's commitment and subsequent policies to reduce emissions are an important determinant of comparative advantage. The channel that I consider builds on the well-established insight that differences in stringency of environmental regulation across countries may result in "pollution havens." As countries with less stringent climate change policies have a lower implied price of GHG emissions, they will have comparative advantage in the production of goods that are more emission intensive. The change in the composition of production resulting from policy changes constitutes an important channel for "carbon leakage."

I examine this hypothesis by testing whether countries with more stringent climate policies export relatively less in industries which are more emission intensive. For emission intensities, I used a measure constructed based mostly on the energy used in the production process. For climate change policies, I used a country's commitment to reduce GHG emissions under the Kyoto Protocol as a proxy.

I find that countries with emission targets under the Kyoto Protocol do tend to produce and export less in more emission intensive industries, compared to those without commitment, and the magnitude of the effect is comparable to traditional determinants of comparative advantage, namely the factor endowments. However, one concern is that countries that chose to abide by binding emission targets under the Protocol could have already been specializing in cleaner industries and have self-selected into the commitment. The panel structure of the trade data allows addressing the issue of endogeneity by analyzing data from the years preceding and after the introduction of the Kyoto Protocol in a number of ways. In particular, I find little evidence that the committed countries exported less in emission intensive industries prior to them signing the Kyoto Protocol. Rather, data suggest that their exports have gradually shifted away from such industries after signing or ratifying the Protocol. This is consistent with the view that the commitment entails more stringent domestic climate change policies and the resulting higher implied price for GHG emission makes the country's comparative advantage shift away from emission intensive industries. Therefore, contrary to the belief that it is not effective, the Kyoto Protocol appears to have exerted a sizable impact on the trade composition of the committed countries. On the other hand, there seems to be no evidence that uncommitted countries have moved toward specializing in emission intensive industries. Therefore, the non-committer side of the industry reallocation channel of "carbon leakage" does not seem to be at work.

The paper is organized as follows. The next section briefly reviews relevant theoretical and empirical literature on international trade and environment. Section III discusses the estimating strategies and the regression equations. Section IV describes the data used. Section V reports the OLS estimates and Section VI tackles the issue of endogeneity. Section VII concludes.

II. 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. Currently, there are 193 parties (192 states and the European Union (EU)) to the Protocol. The major feature of the Protocol is that it sets binding emission targets for the Annex I parties to UNFCCC, which includes 40 industrialized countries and the EU. Table 1 lists the countries that are Annex I parties and reports the targets specified in the Annex B to the Kyoto Protocol[1]. They have committed themselves to national or joint reduction targets, that range from a joint reduction of 8 percent for the EU and others, 7 percent for the United States (US)[2], 6 percent for Japan and 0 percent for Russia. These amount to an average of about five percent against

[1] Since these targets are specified in the Annex B to the Protocol, the committed countries are sometimes referred to a Annex B countries. I will use the term Annex I throughout this paper to avoid confusion. The Annex I countries in this paper refers to the Annex I parties that are committed to a binding emission target under the Kyoto Protocol. It differs from the list of current Annex I members to the UNFCCC as it does not include US, Malta and Turkey. US is not a party to the Kyoto Protocol; Malta was not an Annex I party when it ratified the Protocol and is not currently committed to a binding target; Turkey is placed in a situation different from that of other Annex I Parties and is not under a binding target.

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

1990 levels over the five-year period 2008-2012. The Protocol establishes reporting and compliance systems and introduces market-based mechanisms to help states meet targets. It adopts the principle of "common but differentiated responsibilities[3]," so that emerging and developing countries including major polluters like China or India do not face any binding emission limits. The Kyoto Protocol went into effect in 2005 after Russia ratified the Protocol, overcoming the requirement that the ratified parties incorporate Annex I parties which accounted in total for at least 55 per cent of the total emissions for 1990 of the Parties included in Annex I.

The Kyoto Protocol has been criticized for its lack of credible punishment, and people have worried it will not be an effective international treaty. Nonetheless, a quick look at the total fossil-fuel related carbon dioxide (CO_2) emissions data[4] in the past 20 years suggest that the UNFCCC and the Kyoto Protocol might indeed have had some effect. Figure 1 shows that the total emission from the Annex I countries have experienced much slower increase in the last two decades compared to that from non-Annex I countries and it seemed to have peaked in 2005, when the Kyoto Protocol went into force. In 1990, total emission from Annex I countries is about double of that from non-Annex I countries. By 2006, the emission for non-Annex I countries have become more than that from the Annex I countries, and is keep growing fast. There are of course many reasons that have contributed to the observed path of emissions. Figure 2 gives a closer look at the emissions from different countries or country groups. The Annex I countries with economies in transition (EIT) experienced large decrease in emission due to the decline of their economic activities in the 1990s, which explains

[3]Article 3.1 of UNFCCC states: The 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.

[4]CO_2 is the most important type of greenhouse gases. It represent about 80% of total anthropogenic GHG emission measured in CO_2 equivalent in terms of global warming potential.

the decrease in total Annex I emissions in that period. Nonetheless, emission from other Annex I countries, including US, has increased much more slowly than non-Annex I countries. The increase became even slower in the early 2000s and eventually the emission level peaked in about 2005 or 2006, right before the first commitment period of the Kyoto Protocol. It is therefore reasonable to believe that the Kyoto Protocol indeed have contributed to the much slower growth and peaking of Annex I emission. On the other hand, emission from non-Annex I countries have increased dramatically, with China overtaking US to become the largest emitter in the world by 2006. One has to wonder if the Kyoto Protocol has made Annex I countries become cleaner by shifting emission to non-Annex I countries, possibly through international trade.

Ever since the signing of the Kyoto Protocol, plenty of attention have been paid to analyze it effects with respect to international trade. Since trade and climate change have become two of the most prominent subjects of international cooperation in today's globalized world, the two inevitably found themselves intertwined with each other. The World Trade Organization (WTO) and the UNFCCC recognize and respect each other's mandate and acknowledges the need for meaningful interaction (World Bank, 2009). Unfortunately, the trade and climate change personnel and organizations have largely walked their distinct paths over the years.

In recent years, there has been increased interest from policy makers on the interaction of international trade and the global GHG mitigation effort, as trade may have potentially large yet ambiguous effect on the effectiveness of domestic and global climate change policies. "Carbon leakage" through "dirty" industry reallocation to and lower energy prices in non-participating countries has been an important concern for participants of the Kyoto Protocol. If the emissions policy of a country raises local costs, then another country with a more relaxed policy may have a comparative advantage in industries where such costs associated with emissions are high. If demand for these goods remains the same, production may move offshore to the cheaper countries with lower standards, and global emissions will not be reduced. Mean while on the energy supply side, if environmental policies in one country add a premium to certain fuels or commodities, then the demand may decline and their price 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.

On the other hand, despite all these concerns, various academic studies have suggested that the presence of international trade provides more benefit than harm for combating climate change. International trade in goods may substitute for international trade in emission permits and facilitate more efficient emission reduction by aligning emission abatement cost across countries (Copeland & Taylor, 2001; 2005). In a trading environment, pressure from enhanced environmental regulations and product standards from principal developed-world importers encourages more stringent environmental policy enforcement and compliance and induces technological upgrading and innovation (Zeng & Eastin, 2007; Frankel, 2009). In addition, the international trade of the clean technology and other environmental goods and services may directly contribute to the effort to fight climate change.

With both sides seemingly plausible, it will be useful to empirically estimate the actually effect of existing climate change policies in relation to international trade. So far, there has been little empirical evidence for the "Pollution Heaven Hypothesis" with respect to GHG emission. Yet the potential for "carbon leakage" under deepening regulations cannot be ruled out. With the commitment period of the Kyoto Protocol coming to an end in 2012, it is important to understand the effects of the Protocol so as to shed light on the design and implementation of the successor to the Kyoto regime. This paper therefore attempts to fill the void in the literature on the empirical assessment of the effect of climate change policy, namely the Kyoto Protocol, on international goods trade. By assessing whether it has shifted the patterns of international trade flows, the paper hope to shed light on the important industry reallocation 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 the carbon content of trade or the emission embodied in trade goods. Most of these studies employ input-output analysis to quantify CO_2 emissions embodied in international trade flows. The goal of such analysis is often to calculate the magnitude of emission embodied in imports and exports, and compare to that of domestic production and consumption. For a lot of countries heavily involved in international trade, such differences are substantial and therefore whether a productions based or consumption based measurement of an economy's carbon footprint, or emission inventories (Peters & Hertwich, 2008; Atkinson, et. al., 2010), will have very different implications for responsibilities in the global effort to mitigate greenhouse gas emissions. This paper will use similar data on international trade, but will focus on the variations across industries with varying emission intensities, rather than the overall emission content. In the terminology of the trade and environment literature, this paper will try to deduce the importance of composition effect in potential "carbon leakage", and do not look at scale and technology effects.

The next is the vast literature of Pollution Haven Hypothesis. It build on the intuition that everything else equal, countries or regions with weaker environmental regulation tend to have a comparative advantage in polluting industries and they become pollution haven while opening up to trade. Early studies, mostly utilizing cross-sectional data across countries or industries, do not find significant evidence for the pollution haven hypothesis (see Chua, 1999 for a survey). Part of the reason is that for most industries, pollution abatement costs are a small component of total costs, while those 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 domestic industry location (List, et. al., 2003) , foreign direct investment (FDI) (Keller & Levinson, 2002; Dean, Lovely & Wang, 2009) as well as trade flows (Levinson & Taylor, 2008; Broner, et. Al, 2011). This paper draws on similar strategies to identify the potential source of comparative advantage in emission intensive industries.

The last line of literature concerns with the economic impact of existing and potential climate change policies. Prospective studies of the EU Emission Trading System (ETS) have shown that concern over the system's potential impacts on trade flows should be limited to a small set of industrial sectors (Grubb, et. al., 2007). Studies focusing on specific sectors under EU ETS found overall leakage of EU emissions is unlikely to be greater than 1 percent, but that impacts on EU production and imports could be significantly larger in the iron and steel and cement sectors (Demailly & Quirion, 2006; 2008). Other studies have found large magnitudes of carbon leakage of over 40 percent (Aichele & Felbermayr, 2010) or higher. A World Bank study (2008) concludes that both carbon taxes and energy efficiency standards have a statistically significant negative effect on competitiveness suggested by their impacts on bilateral trade flows, particularly for industries that are subject to higher energy efficiency standards and are not subsidized by governments. The current research will attempt to complement the limited empirical literature on the effect of climate change policies on international trade by exploring more than the most emission intensive industries. In sum, this paper draws on the empirical estimation strategies from the "Pollution Haven" literature, takes an alternative approach of analyzing trade flows to input-output analysis, and attempts to shed light on the issue of "carbon leakage" on a broader scope.

III. Empirical Strategy and Estimation Equations

To test the effectiveness of the Kyoto Protocol and identify potential “carbon leakage,” I would like to analyze the effect of climate change policy on the pattern of international trade. My empirical analysis is informed by recent developments in quantitative general equilibrium models of trade. Eaton and Kortum (2002) develope a multi-country Ricardian model of international trade with a continuum of goods, based on differences in technology, that captures the forces of comparative advantages as well as geographical barriers. Their probablistic 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 in order to quantify the importance of various sources of comparative advantage within a common framework. Chor’s model explains the cross-country patterns of specialization and industry trade flows based on the intuition that industries vary in the factors and institutions 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 to assess determinants of comparative advantage,

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

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 exporter i, s_f^k the share of factor f in production for industry k, L_{il} an institutional measure l for country i, M_{km} 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's the error terms. Log bilateral industry trade flows are regressed on (i) H-O forces, through the interaction of country factor prices, $\ln \frac{\omega_{if}}{\omega_{i0}}$, and industry factor shares, s_f^k; (ii) institutional forces, captured by the interaction between country institutional measures, L_{il}, and industry measures of dependence, M_{km}; (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) exporter fixed effect, α_i, which absorbs any exporter specific characteristics that have common effects on trade flows across industries and importer; and (v) importer-industry fixed effect, α_{nk}, which collects such factors as specific industry demand in an importing country or an industry specific tariff rate of an importer, provided it does not vary across exporters. Standard errors are clustered by exporter importer pair, to allow for correlated shocks among bilateral observations υ_{ni}. This estimation equation embeds the empirical specification of recent studies on sources of comparative advantage ranging from factor endowments (Romalis, 2004), to institutional sources such as financial development (Beck, 2003) and legal institutions (Levchenko, 2007; Nunn, 2007).

To implement equation 1 for my analysis on comparative advantage in emission intensive industries, I can treat the stringency of climate change policies as an institutional measure and use emission intensities as the dependency score of each industry on a country's climate change institutions. Alternatively, I can view emission intensity as analogous to factor shares and use the stringency of climate change policies to approximate for the relative emission prices. In fact, a common practice in the trade and environment literature is to model pollution emission as a factor of production in the trade and environment literature. Drawing on the theoretical work of Copeland and Taylor (2001), Broner, et al. (2011) extends Chor's model to include pollution as an additional factor for production and proposes an estimation equation to analyze comparative advantage in polluting industries, which is similar to the following form, omitting the institutional terms,

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

where the added term is the interaction of industry pollution expenditure share, s_E^k, and the relative price of pollution 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 emission per output. Only when the price for emission τ_i is high enough and firms actively engage in emission abatement will emission price factor into the cost function. In a world where this is not the case in any country, β_E is zero and equation 2 reduces to equation 1. However, estimation of equation 2 may still find β_E significantly different from zero if the emission interaction term is correlated with other factors that determines the pattern of industry trade flows. When the emission 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 emission prices and the indirect general equilibrium production reallocation effect that countries with non-binding emission prices are also affected.

I will apply equation 2 to this study using stringency of climate change policies to proxy for the relative emission price, $\ln \frac{\tau_i}{\omega_{i0}}$. In particular, I will use the indicator variable for Annex I status under the Kyoto Protocol CP_i. A number of previous studies have also utilized the same measure as a proxy of the stringency of climate change policy (Aichele & Felbermayr, 2010; Yörük and Zaim, 2008). The underlying assumption is that there is a link between Kyoto commitment and actual climate policies that potentially result in higher emission prices. This policy measure may be correlated with other country characteristics or institutional measures that may potentially affect trade patterns. In particular, Annex I countries are mostly high income countries that tend to have good legal and financial institutions. If an industry's dependency on such measures is correlated with emission intensities, ignoring them will render estimates for the coefficient on the climate change policy-emission intensity interaction biased. I will therefore try to control for various country characteristics and institutional measures. 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. It is, however, feasible to generate an emission interaction term for each of the Annex I countries using indicator variables. One can then observe the coefficients for each countries and check if there is an interesting pattern in the heterogeneity. For the industry emission expenditure share s_E^k, I will use the measure of CO_2 emission intensity, i.e., the amount of CO_2 emitted per unit of value added, which I will discuss in detail in the next section.

In this paper, I will use US imports data for empirical estimation. When estimating equation 2 with only one importer, all the bilateral distance variables $\beta_d D_{ni}$ and the bilateral error term υ_{ni} will be absorbed into the exporter fixed effect α_i. Following standard practice in the literature, I use factor endowment ratios in the place of factor price ratios. The main 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 US imports are regressed on the interaction of Annex I status CP_i and CO_2 emission intensities s_E^k, factor interactions $\left(\ln \frac{V_{if}}{V_{i0}}\right) s_f^k$ and exporter and industry fixed effects α_i and α_k. Because of data availability at the level of analysis, I do included a wide range of possible determinants of comparative advantage. Though there will not be a serious problem as long as they are not correlated with the emission interaction, these unobserved variables may make the error terms correlate for a given exporter or an industry. To accommodate such correlations, errors will be two-way clustered by exporter and industry.

One potential concern for the estimation is that of endogenous selection. It is conceivable that the countries that were already specializing in less emission intensive industries, or self-selected to become Annex I parties to UNFCCC and ratify the Kyoto Protocol. To provide evidence of the extent to which this is the case, I exploit the panel structure of the trade data and address the endogeneity problem in several ways.

First, I do a regression using the full panel spanning the years before and after the signing of the Kyoto Protocol. I introduce two versions of the dummy variable for Annex I status, and run the following regression

$$\ln(M_{i,t}^k) = \beta_E^R CP_{i,t}^R s_E^k + \beta_E CP_i s_E^k + \sum_{f=1}^{F} \beta_f \left(\ln \frac{V_{if}}{V_{i0}}\right) s_f^k + \alpha_{i,t} + \alpha_{k,t} + \upsilon_{i,t}^k \qquad (4)$$

where trade flows $M_{i,t}^k$ are now also index by year t, and the fixed effects are now specified as exporter-time $\alpha_{i,t}$ and industry-time $\alpha_{k,t}$. Errors are still two-way clustered by exporter and industry. CP_i is time invariant, denoting whether country i is committed under the Kyoto Protocol, while $CP_{i,t}^R$ is only positive starting the year after the country ratified the Kyoto Protocol. By including both as explanatory variables, the estimation can provide evidence on the extent to which there were preexisting patterns of specialization in emission intensive industries before the signing of the Kyoto Protocol and the extent to which there are changes in trends following the ratification of the Protocol. Thus, I can identify if ratification of the Kyoto Protocol indeed institutes more stringent climate policy that significantly affects patterns of trade.

Alternatively, I estimate equation 3 for every year from 1990 to 2010. I then check whether the β_E is significant before the signing of the Kyoto Protocol or is only the case after the Protocol entered into force. Compared with the single regression of equation 4 using the full sample, the series of regressions is more flexible to the extent that the coefficients on the factor interactions are allowed to differ over time, however, it does not capture the differences in the year of each Annex I parties ratified the Kyoto Protocol.

I also analyze the difference of 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. By first differencing the log trade flows between two years before and after the entry into force of the Kyoto Protocol and regressing them on the interaction of Annex I status and emission intensity, I test if there is significant impact of the change in climate policy on the change in trade patterns. This method will control for all time invariant factors that affect trade flows. I obtain the following specification by first differencing equation 3,

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

where $\Delta \ln(X_i^k)$ 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 tightening of climate change policy, and the fixed effects $\Delta\alpha_i$

and $\Delta\alpha_k$ now control for changes in the country and industry specific factors that contribute to the change in trade flows, such as a country signing a trade agreement with US or an increase in US 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 factor shares s_f^k and country factor endowments $\left(\ln \frac{V_{if}}{V_{i0}}\right)$, have not changed over the period. Hence, these interaction terms drop out if the coefficients β_f remain unchanged. One complication is that before Kyoto, the cost of emission may not be part of the cost function of firms, and therefore the coefficient for other factor share and factor endowment interaction terms may indeed be different. For robustness, I report estimation results with the factor interaction terms as well. The estimated coefficients now signifies change in the previously described coefficients $\Delta\beta_f$. To explore whether there is any evidence of a preexisting trend in Annex I countries toward specializing in less emission intensive products, I conduct a similar regression on first differenced log trade flows between two years before the Kyoto enters into force and check if β_E is significant.

So far we have exploited the difference between the climate change policies of the Annex I and non-Annex I countries to test if the Kyoto Protocol has had an effect on trade patterns. It is also informative to separately analyze the pattern of specialization with respect to industry emission intensity for the two groups of countries. The last exercise I do is to estimate the following equation for the respective groups,

$$\ln(M_i^k) = \beta_E s_E^k + \sum_{f=1}^{F} \beta_{fs} s_f^k + \sum_{f=1}^{F} \beta_f \left(\ln \frac{V_{if}}{V_{i0}}\right) s_f^k + \alpha_i + v_{ni}^k \qquad (6)$$

where log imports M_i^k, is regressed on emission 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 the Annex I status within the Annex I and non-Annex I groups, the emission interaction term reduces to emission intensities. Therefore industry fixed effects cannot be included while industry factor shares are added in. Estimation of of equation 6 will allow comparison between the Kyoto Protocol's direct effect on committed countries and the indirect effect on non-committed countries with respect to specialization in emission intensive industries. If the Kyoto induced "carbon leakage" is strong enough, one would expect β_E to be negative for Annex I countries and positive for non-Annex I countries.

IV. Data

CO_2 Emission Intensities.—Due to data availability, industry level CO_2 emission intensities are created only US data. Data on industry CO_2 emissions intensities are from a report of Economics and Statistics Administration of US Department of Commerce (ESA, 2010). The report analyzes energy-related CO_2 emissions and intensities for all Iliad[5] industries, government and households in the US for the 1998 to 2006 period. 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, such as cement and lime, are also considered. The intensities are measured in emissions produced per unit value of gross output, and reported for the three years of 1998, 2002 and 2006. For manufacturing industries, I am able to adjust such measures by the gross output to value added ratios of the industries to obtain intensities in terms of direct emissions per value added, which are more consistent with treating emission as a factor of production. For agriculture and mining industries, value added data are only available at a more aggregated level. Therefore for analysis of all industries, I

[5]Iliad stands for Interindustry Large-scale Integrated And Dynamic model of the U.S.. See Data Appendix for details.

use total emissions, including direct emissions in production and emissions embodied in intermediate inputs, over total output. For the set of industries for which both measure are available, i.e., the manufacture industries, the correlation between the output and the value added based measures is very high, at about .98, as shown in Table 2. Table 4 list the ten most and the ten least emission intensive industries. The most emission intensive industries are lime, cement, fertilizer and a few mining industries. The list is broadly consistent with those identified by previous studies as the energy intensive industries that may be affected by climate regulations the most (EPA, 2009). The least emission intensive industries are tobacco products and high-tech industries.

I treat emission intensity as a time and country invariant characteristic of industries and use the average of the measures over 1998, 2002 and 2006 for all our analysis. Over the period, the measured emission intensities are on a general decreasing trend and the average emission intensity of US 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 emission reduction in the U.S., compared to industry reallocation or composition changes (Levinson, 2009). However, since the main objective of this paper is to explore the potential effect of relative emission intensities across different industries on the patterns of international trade, I only need the relative intensities to remain stable over time, i.e., an emission intensive industry before Kyoto kept being emission intensive relative to other industries in the economy afterwards. As shown in Table 3, this is indeed the case as the correlation between the measures from the three years (panel (1) and (2), over .96) as well as the ranking of these measures (panels (3) and (4), over .88) are very high.

Similar to previous studies, since I only have detailed data on emission for US industries, I also need to assume that the relative intensities is the same across economies. I recognized that there is substantial difference due to technological development, resulting in different emission intensities in different countries, evidenced by large differences in emission per capita and emission intensities of the general economy. I implicitly assume that advances in abatement technology is not biased toward particular industry, rather it applies in general to all industries. If we believe most of development in the CO_2 emission abatement technologies apply to the energy sector, then our assumption is valid, as all other industries consume the produced electricity or fuel and all benefit from the technological advances.

Climate Change Policy.—I use the Annex I membership to UNFCCC as a proxy of a country's climate change policy. In particular, if a country is an Annex I party, it commits to reduce or limit its emission levels relative to a baseline (in most cases the 1990 emission level) under the Kyoto Protocol. The underlying assumption is that a country that commits to reduce emissions will adopt policy measures such as cap-and-trade, taxes and efficiency standards that puts a price on the price of CO_2 emissions. Firms in the economy will bear such cost either directly through abatement or indirectly through increased prices of electricity and other inputs.

As discussed in Section III, I introduce two versions of the measure. The time invariant Annex I dummy assigns 1 to a country if it is currently an Annex I party. The other dummy assigns 1 to an Annex I party only starting the year after it has 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) or when the Protocol actually went into force for the country (the later of Feb., 2005 or 90 days after ratification). All yield similar results for our estimation.

Other variables.—Data on trade flows, factor endowments, factor intensities of production and other country characteristics are from standard sources. US import data in Harmonized System (HS) 10-digits are from US Census, 1990 to 2005 from Schott (2008), 2006 to 2010 from Census Disks. Data are then aggregated to Iliad industry level, using HS to the North American Industry Classification System (NAICS) concordances provided by the Census and Pierce and Schott (2009), and NAICS to Iliad concordances from the Interindustry Forecasting Project at the University of Maryland (Inforum). The panel of trade flows is unbalanced. There are many zeros or missing data, so the estimation results must be interpreted as conditional on positive trade flows. I also use the data on output and export of ISIC3 4 digit industries from 70 countries obtained from Industrial Demand-Supply Balance Database of UNIDO (2011).

Capital endowment is proxied by the capital-labor ratio from Extended Penn World Tables (EPWT) (Marquetti, 2011), averaged for years 1990 to 2009. Human capital is proxied by average years of education for Barro & Lee (2001). I use the data from 2000, which is the latest available, in our estimation. For countries where the 2000 data are missing but 1995 or 1990 data are available, I update the older data based on a quadratic estimation of 2000 measures from 1995 or 1990. 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 by the U.S. Census Bureau. 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 emission per capita and CO_2 intensity of

GDP for each year from EPWT. I obtain a measure of stringency of a country's environmental regulations from Global Competitiveness Report (2007).

V. Empirical Results

Emission Content of US imports.—Before I present the estimation results, I take a look at some raw data available to see if the they lend support to the hypothesis that the Kyoto Protocol has an impact on patterns of trade. Using U.S. emission intensities, constant for all years, I calculate the proportion of CO_2 emissions embodied in imports of US, or the displaced US emission by importing, from non-Annex I countries. Figure 3 shows that over the period of study, there is a steady increasing trend from 37 percent in 1990 to 53 percent in 2010. It seems to suggest that the U.S. is importing more of embodied carbon from countries with less stringent climate policy. However, an apparent explanation is that US is just importing more goods from non-Annex I countries, which includes fast growing emerging economies. Indeed, the proportion of total US imports from non-Annex I countries is almost parallel to the proportion of "carbon imports." Nonetheless, if we consider that non-Annex I countries also tend to use out-dated more emission intensive technologies in production compared to Annex I countries, then the increase in proportion of "carbon imports" from non-Annex I countries may be increasing faster than that of the value of imports. Potentially, "carbon leakage" as a result of unilateral commitment to emission abatement could be happening. Another interesting observation is presented in Figure 4. Non-Annex I countries seems to have a large share of total output from emission intensive industries, while they do not seem to be exporting proportionally more than Annex I countries in these industries. To explore more rigorously on the impact of Kyoto Protocol on the pattern of trade, I present the estimation results.

Baseline Results.—I present here as baseline result a pure cross-sectional analysis of the data of US 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, being the last year before the first commitment period. 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 Annex I countries export less in emission intensive industries, which is consistent with the hypothesis that climate change policy is important for comparative advantage. In particular, it implies that for an industry with an emission intensity half a standard deviation above the mean, such as the glass containers industry, an Annex I country will export on average a little over 20 percent less to the U.S. than an non-Annex I country, controlling for general effects of country characteristics on all industries. This effect is similar whether I consider all industries (column (1) of Table 5) 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 emission intensity.

CO_2 emission intensive industries are essentially energy intensive industries, which are also likely capital intensive. Annex I countries are high income countries, generally with higher capital labor ratio than non-Annex I countries. Therefore one would worry that the results presented above are merely a reflection of the endowment of capital as a determinant of comparative advantage. Regression results with controls for factor endowments as determinants of comparative advantage is reported in column (4) Table 5. Adding controls for capital and skill interactions does reduce the magnitude of the estimated coefficient on the emission interaction, however, it remains significant at 5 percent level, which suggests that the emission intensity and

Annex I status interaction is not merely capturing other classical determinants of comparative advantage. In addition, the magnitude of the effect of the emission intensity interaction is similar to the factor intensity interactions. The estimated coefficient on the average measure of pollution intensity implies that an Annex I country would export 29 percent less to the U.S. than a non-Annex I country in an industry with an emission 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 percent more in an industry with a skill share one standard deviation above the mean. Surprisingly, capital intensity does not seem to have a significant effect.

Robustness.—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 US 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 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 emission 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 therefore estimate equation 3 including controls for interactions of emission intensity with emission per capita, emission intensity of overall economy and income per capita. The results reported in columns (2)-(4) of Table 6 show that the coefficient on the original interaction do not a lot and remain significant. It suggests that Annex

I status is capturing more than the effect of aforementioned country characteristics On the other hand, the status is highly correlated with the stringency of a country's environmental regulations, at about .8. This is not surprising since the climate change policies constitute part of the overall environmental regulations. As a result, the interaction term of emission intensity with Annex I status becomes insignificant when controlling for interaction term with the finer measure of stringency (column (5)).

A closely related concern as a result of the use of a binary variables is that only an average effect of commitment under the Kyoto Protocol is identified. It is informative to investigate if there are substantial variations in the effects across countries. To explore the potential differences, I regress the log imports on interactions of emission intensities with dummy variables for each of the Annex I countries. As Figure 8 shows, there are indeed large difference between individual countries. Russia, Belarus and a few others have a significantly positive coefficient on the emission interaction term, suggesting that they actually tend to specialize more in emission intensive industries relative to an average non-Annex I country. The result is not quite surprising. With the exception of Greece, all the countries with a positive coefficient are EIT countries. With their economies in drastic transition in the 1990s, these countries tend to have a much lower emission level compared to the base years around 1990 as well as their committed targets under the Kyoto Protocol (see Figure 2 and Table 1). Therefore, there is not much pressure for such countries in meeting their commitment in the 2008-2012 period and hence little incentive to ramp up climate change regulations. There are, however, exception in the EIT group, as Czech Republic, Slovakia, Hungary and Poland are among those with the most negative coefficients. These four countries were among the first EITs to join the EU in 2004 and it is possible that they have taken the opportunity to restructure their economy to be green. The result echoes with earlier finding by Yörük and Zaim (2008) that Poland and Hungary are the best in environmental performance among OECD countries[6], while Czech Republic and Slovakia both score fairly high, at just over one standard deviation above the mean, in terms of stringency of environmental regulation in the 2007 Global Competitiveness Report.

VI. Endogeneity

As discussed in section III, one must be cautious in interpreting the OLS results presented in the previous section. This is because that causality may run from trade flows to climate change policy. Countries may have chosen to become Annex I members of the Kyoto Protocol when they were already specializing in less emission intensive industries. To address this concern, I exploit the panel structure of the data on trade flows and present three sets of results to provide evidence against this potential alternative explanation.

Changes in Climate Policy.—As explained in section III, I pool the cross sectional data for each year and use the full panel for an estimation of equation 4. I characterize the change in the regression coefficient of the interaction term of emission intensity and Annex I membership before and after a country ratifies the Kyoto Protocol, by including two sets of interaction variables. One of the interaction is time invariant, based on a country's commitment under the Kyoto Protocol and the other time variant, only positive for years after a country's ratification of the Protocol. 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

[6] Slovak Republic and Czech Republic are excluded from Yörük and Zaim's (2008) analysis due to the unavailability of the data.

industries in the same manner for a given country year.

As shown in Table 7, when I include both versions of the interaction term (columns (2) and (4)), the coefficient on the time-invariant one is a little more than half of the magnitude of the coefficient of the time varying status as a single regressor (columns (1) and (3)), suggesting that Annex I countries had been exporting less in emission intensive industries before they ratified the Kyoto Protocol. However, this effect is only significant at the 10 percent level. On the other hand, the coefficient on the time-varying term is highly significant and is also about half the magnitude of the coefficient on time varying emission interaction term as a single regressor. It shows that Annex I countries experience a reduction in exports in emission intensive industries following their ratification of or accession to the Kyoto Protocol. This suggests that ratifying the Kyoto Protocol does signal a more stringent climate change policy and higher costs of emission made committing countries export even less in CO_2 intensive industries.

Regression of Differences.—A related approach to examine the impact of the Kyoto Protocol in changing export patterns is to estimate equation 5, with the specification in log differences. As discussed in section III, 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 regress now control for the average growth rate of industry trade flows of each exporter and the average growth rate of country trade flows for a particular 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 becoming and Annex-I member mattered for the patterns of trade. I look at changes between 1992 and 1999 and that of 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 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 8 shows that the effect on the changes of US import volume is significant for the Kyoto period, but not for the pre-Kyoto period. This suggests that committing to emission abatement through becoming an Annex-I party to the Kyoto Protocol does make a country export less in emission intensive industries relative to non-committed economies.

Trends.—Another 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 emission intensities have changed before and after the Kyoto Protocol. This approach is more general than the previous specification of equation 4 with post-ratification interaction, as it allows the coefficient on Annex I status to vary flexibly over time. It enables me to look at pre-trends as well as initial level differences. Figure 7 presents the series of coefficients on the emission interaction term along with 95 percent confidence bands.

The coefficient seems to be rather flat and not different from zero until year 2000, after which there is a clear downward trend. Eventually, it becomes statistically different from zero. This is consistent with the previous results that there is a week pattern of Annex I parties exporting less emission intensive goods before the Kyoto Protocol. However, the policy change signified by the ratification of the Protocol does have statistically significant effect. Namely, the pattern that an Annex I party export less in emission intensive industries becomes stronger after the adoption of the Kyoto Protocol in later 1997 and eventually becomes statistically significant from zero as it approaches the commitment period of the Protocol. The fact that the coefficient is close to zero and not moving much suggests that there does not appear to be a preexisting trend for the Annex I countries to shift toward cleaner exports. Thus endogenous selection is not a great issue for my analysis.

I further analyze the two sets of countries separately, estimating equation 6. For Annex I countries and non-Annex I countries, I separately regress trade flows on emission intensity controlling for factor shares and factor endowment-factor share interactions with country fixed effects. This specification further allows me to analyze the trade patterns of the two sets of countries with respect to emission intensity, rather than focusing on their differences. It also allows the coefficients on the H-O forces to differ for the two groups of countries, which according to the theory behind the estimation equations could indeed be the case if the price of emission is negligible in non-committing countries. The evolution of the coefficient on emission intensity in presented in Figure 6. It is clear that although the coefficient for the Annex I countries is generally below zero and that for non-Annex I countries about zero, they are not significantly different from each other until later in the period. Starting in the late 1990s, concurrent with the signing of the Kyoto Protocol, there seems to be a diverging trend. Most of the increasing differences between the two is because of the decreasing trend of the coefficient for Annex I parties. It suggests that the effect of the more stringent climate policy indeed mainly affects the countries that adopt them. There seem to be little evidence that non-committing countries are moving toward specializing in more emission intensive industries. This is an interesting observation that it suggests the general equilibrium relocation of production does not seem have happened therefore the dreaded "carbon leakage" may not be as serious as some have feared, at least through the production relocation channel. Of course, since our data is limited to US imports, this could be explained by a change in US domestic production moving toward more emission intensive industries or the US demand moving toward less emission intensive industries. It warrants further analysis

Exploiting the panel structure of the data, I have been able to address the potential selection issue. I find no evidence that Annex I countries specialized less in emission intensive industries prior to the adoption of the Kyoto Protocol. Rather, there is a statistically significant decline in their specialization in these industries following their ratification of the Protocol. This pattern of results 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.

VII. Conclusion

In this paper I attempt to empirically assess the impact of climate change policies on economic activities using detailed data on industry emission intensities and trade flows. Using estimation strategies informed by recent developments in the quantitative general equilibrium of international trade, I find that climate change regulations are an important determinant of comparative advantage in emission intensive industries. In particular, countries that commit to binding emission targets under the Kyoto Protocol export less in emission intensive industries. The result is robust to a variety of controls of comparative advantage and the magnitude of the effect is comparable to that of factor endowment. Exploiting the panel structure of the data, I show there is indeed a statistically significant trend of committed countries shifting exports toward less emission intensive industries that emerged after the introduction of the Kyoto Protocol, which cannot be explained by any trend previously existed.

My analysis suggests that despite skepticism of its effectiveness, the Kyoto Protocol does have a effect on the organization of trade production, which may lead to reduction of GHG emissions in countries with binding commitments. On the other hand, there is little evidence that there is generally equilibrium production relocation which may contribute to sizable "carbon leakage." Therefore, adoption of carbon motivated boarder adjustments to address the leakage concern may be not be desirable Given significant differences in the technological differences across countries, attention of policy making may be better directed at facilitating technological transfer and other mitigation and growth potentials (UNCTAD, 2010).

REFERENCES

Aichele, R. & Felbermayr, G. (2010). "Kyoto and the carbon content of trade," FZID Discussion Paper 10-2010.

Atkinson, G., Hamilton, K. Ruta, G. & van der Mensbrugghe, D. (2009).. "Trade in 'virtual carbon': Empirical results and implications for policy," Background paper to the 2010 World Development Report, Policy Research Working Paper 5194.

Barro, R. J. & Lee, J.-W. (2000). "International Data on Educational Attainment: Updates and Implications", CID Working Paper No. 42.

Becker, R. A. & Gray, W. B. (2009). "NBER-CES manufacturing industry database." Available at http://www.nber.org/data/nbprod2005.html.

Boden, T.A., Marland, G., & Andres, R. J. (2011). "Global, regional, and national fossil-fuel CO_2 emissions," Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, U.S. Department of Energy, Oak Ridge, Tenn., U.S.A. doi 10.3334/CDIAC/00001_V2011

Broner, F., Bustos, P. & Carvalho, V. M. (2011). "Sources of comparative advantage in polluting industries." Unpublished.

Chor, D. (2010). "Unpacking sources of comparative advantage: A quantitative approach," *Journal of International Economics*, *82*, 152-167.

Chua, S. (1999) "Economic growth, liberalization, and the environment: A review of the economic evidence," *Annual Review of Energy and the Environment*, *24*, 391-430.

Copeland, B. R. & Taylor, M. S. (2001). "International trade and the environment: A framework for analysis," NBER Working Paper No. 8540.

Copeland, B. R. & Taylor, M. S. (2005). "Free trade and global warming: A trade theory view of the Kyoto Protocol," *Journal of Environmental Economics and Management*, *49*, 205-234.

Demailly & Quirion, 2006

Demailly, D. & Quirion, P. (2008). "European Emission Trading Scheme and competitiveness: A case study on the iron and steel industry," *Energy Economics*, *30*, 2009-2027.

Dinda, D. (2004). "Environmental Kuznets curve hypothesis: A survey," *Ecological Economics*, *49*, 431-455.

Douglas, S. & Nishioka, S. (2009). "International differences in emissions intensity and emissions content of global trade," Working Papers 09-02, Department of Economics, West Virginia University.

Eaton, J. & Kortum, S. (2002). "Technology, geography, and trade," *Econometrica*, *70*, 1741-1779.

Ederington, J., Levinson, A. & Minier, J. (2005). "Footloose and pollution-free," *The Review of Economics and Statistics*, *87*, 92-99.

Frankel, J. (2009). "Environmental effects of international trade," HKS Faculty Research Working Paper RWP09-006.

World Economic Forum. (2007). *The Global Competitiveness Report 2007-2008.* Geneva: World Economic Forum.

Grubb, M., Brewer, T., Sato, M., Heilmayr, R., & Fazekas, D. (2009). "Climate policy and industrial competitiveness: Ten insights from Europe on the EU Emissions Trading System," German Marshall Fund. Available at: http://www.climatestrategies.org/component/reports/category/61/204.html.

Grunewald, N. & Martínez-Zarzoso, I. (2011). "How well did the Kyoto Protocol work? A dynamic-GMM approach with external instruments," Ibero America Institute for Econ. Research (IAI) Discussion Paper 212.

Karp, L. (2010). "Reflections on carbon leakage." Unpublished.

Karp, L. (forthcoming). "The environment and trade: A review," forthcoming, *Annual Review of Resource Economics.*

Keller, W. & Levinson, A. (2002). "Pollution abatement costs and foreign direct investment inflows to U.S. states," *The Review of Economics and Statistics*, *84*, 691-703.

Levchenko, A. (2007). "Institutional quality and international trade," *Review of Economic Studies*, *74*, 791-819.

Levinson, A. (2009). "Technology, international trade, and pollution from US manufacturing," *American Economic Review*, *99*, 2177-2192.

Levinson, A. & Taylor, M. S. (2008). "Unmasking the pollution haven effect," *International Economic Review*, *49*, 223-254.

List, J. A., Millimet, D. L., Fredriksson, P. G., & McHone, W. W. (2003). "Effects of environmental regulations on manufacturing plant births: Evidence from a propensity score matching estimator," *The Review of Economics and Statistics*, *85*, 944-952.

Marquetti, A. (2011). "Extended Penn world tables." Available at http://homepage.newschool.edu/~foleyd/epwt/.

Nunn, N. (2007). "Relationship-specificity, incomplete contracts, and the pattern of trade," *The Quarterly Journal of Economics*, *122*, 569-600.

Peters, G. P. & Hertwich, E. G. (2008). "CO_2 embodied in international trade with implications for global climate," *Environmental Science and Technology*, *42*, 1401-1407.

Pierce, J. R. & Schott, P. K. (2010). "Concording U.S. Harmonized System codes over time." Available at: http://faculty.som.yale.edu/peterschott/sub_international.htm.

Romalis, J. (2004). "Factor proportions and the structure of commodity trade," *American Economic Review*, *94*, 67-97.

Schott, P. K. (2008). "The relative sophistication of Chinese exports," *Economic Policy*, *23*, 5-49.

Su, B., Huang, H. C., Ang, B. W., and Zhou, P. (2010). "Input–output analysis of CO_2 emissions embodied in trade: The effects of sector aggregation," *Energy Economics*, *32*, 166–175.

UNCTAD. (2010). *Trade and environment review 2009/2010: Promoting poles of clean, sustainable growth in developing countries to enhance resilience to the inter-related economic, food and climate crises*. New York and Geneva: United Nations Publications.

UNFCCC. (2011). *Total CO_2 Equivalent Emissions without Land Use, Land-Use Change and Forestry.* Available at: http://unfccc.int/ghg_data/ghg_data_unfccc/time_series_annex_i/items/3814.php.

UNIDO. (2011). *Industrial Demand-Supply Balance Database, 2011 edition at the 4-digit level of ISIC Revision 3.* Vienna, Austria: Statistics and Information Networks Branch, UNIDO.

U.S. Census Bureau. (2007-2011). *U.S. Imports Merchandise Trade, 2006-2010.* Washington, DC: U.S. Census Bureau.

U.S. Census Bureau. (2007, 2009-2010). *Annual Survey of Manufactures (ASM), 2006, 2008-2009.* Available at: http://factfinder.census.gov/servlet/DatasetMainPageServlet?_program=EAS.

U.S. Census Bureau. (2008). *2007 Economic Census and Surveys.* Available at: http://factfinder.census.gov/servlet/DatasetMainPageServlet?_program=ECN.

Economics & Statistics Administration, U.S. Department of Commerce. (2010). "U.S. carbon dioxide emissions and intensities over time: A detailed accounting of industries, government and households." Available at: http://www.esa.doc.gov/Reports/u.s.-carbon-dioxide.

U.S. Environmental Protection Agency. (2009). "The effects of H.R. 2454 on international competitiveness and emission leakage in energy-intensive trade-exposed industries." Available at: http://www.epa.gov/climatechange/economics/pdfs/InteragencyReport_Competitiveness-EmissionLeakage.pdf.

Yörük, B. K. & Zaim, O. (2008). "International regulations and environmental performance," *Applied Economics*, *40*, 807-822.

Zeng, K. & Eastin, J. (2007). "International economic integration and environmental protection: The case of China," *International Studies Quarterly*, *51*, 971-995.

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

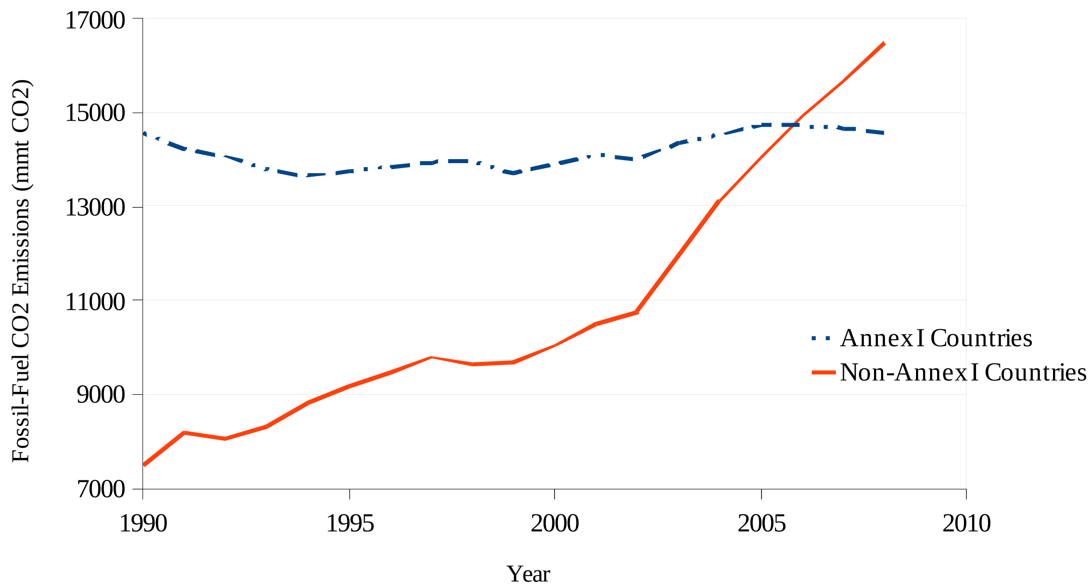

Figure 2: Fossil-Fuel CO_2 Emissions from Selected Country Groups

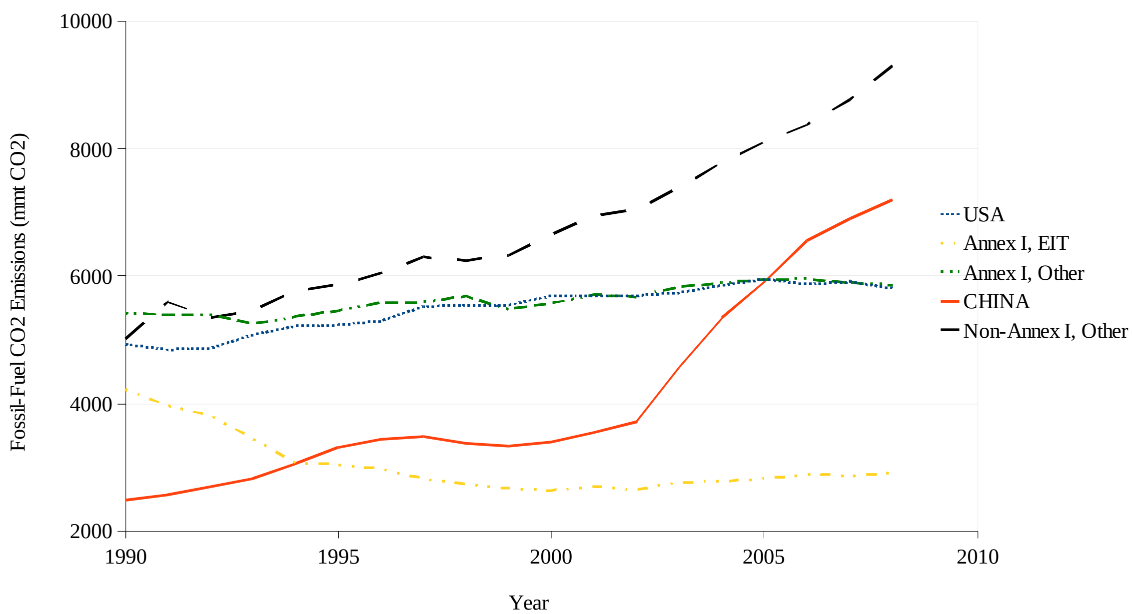

Figure 3: Proportion of Imports from Non-Annex I Countries

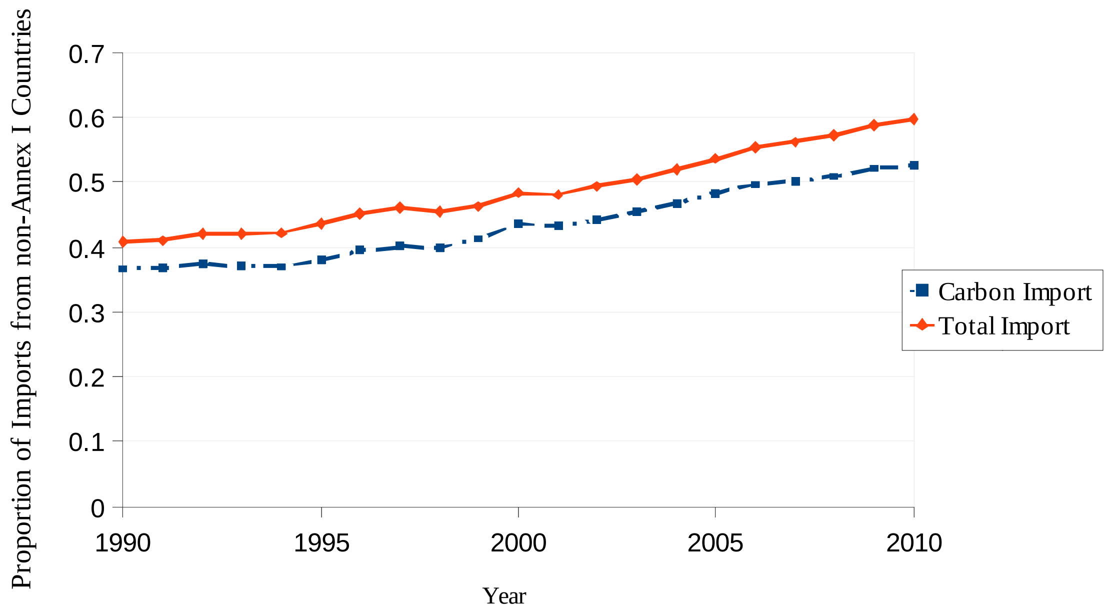

Figure 4: Cumulative Proportion of Manufacturing Output/Export

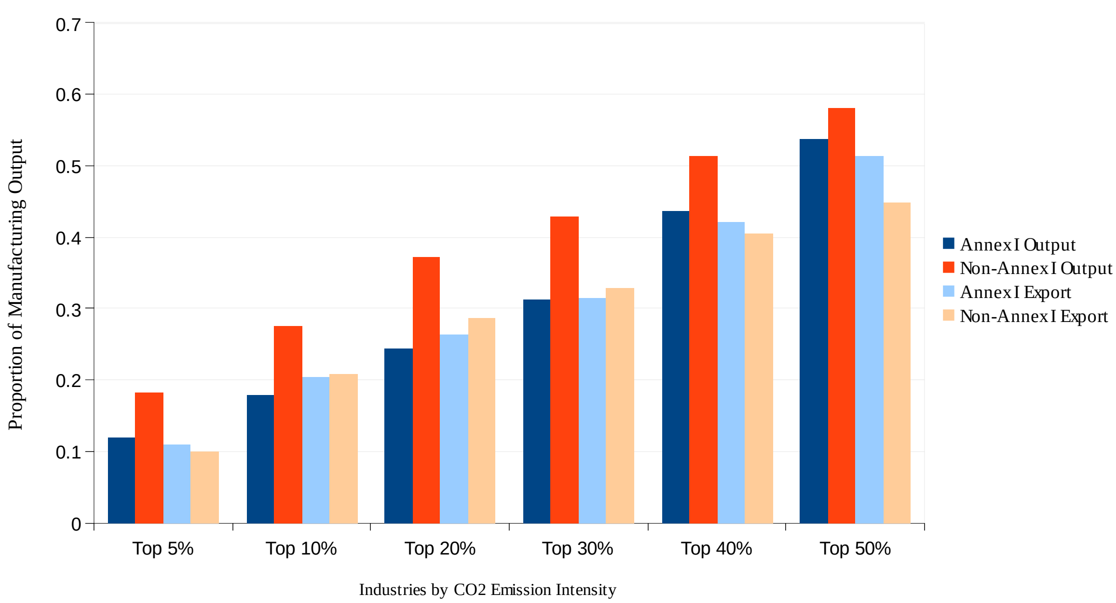

Figure 5: Coefficient on Emission Intensity x Annex I status

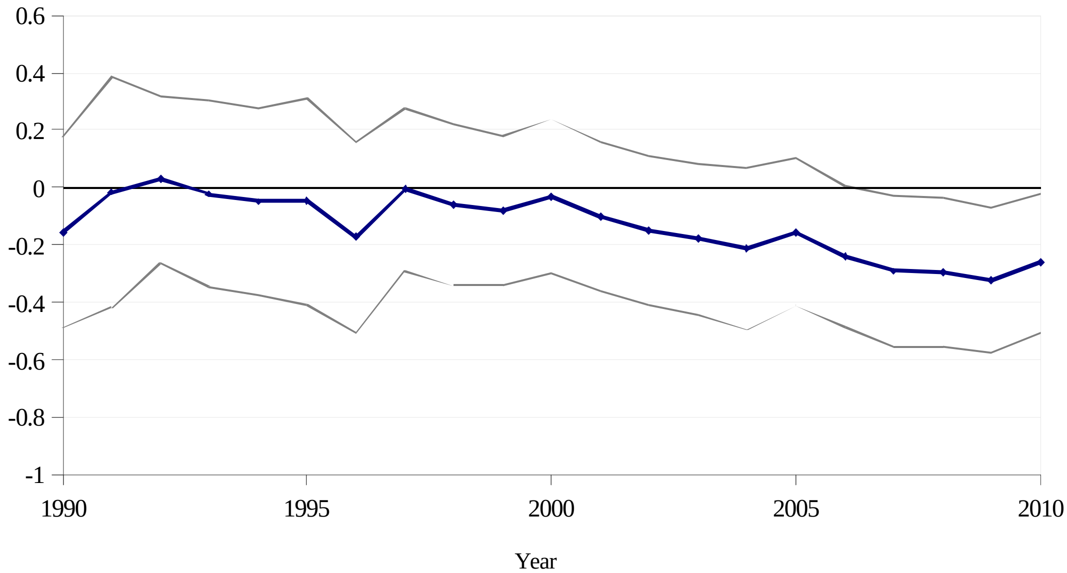

Figure 6:

Figure 7: Coefficient of Emission Intensity

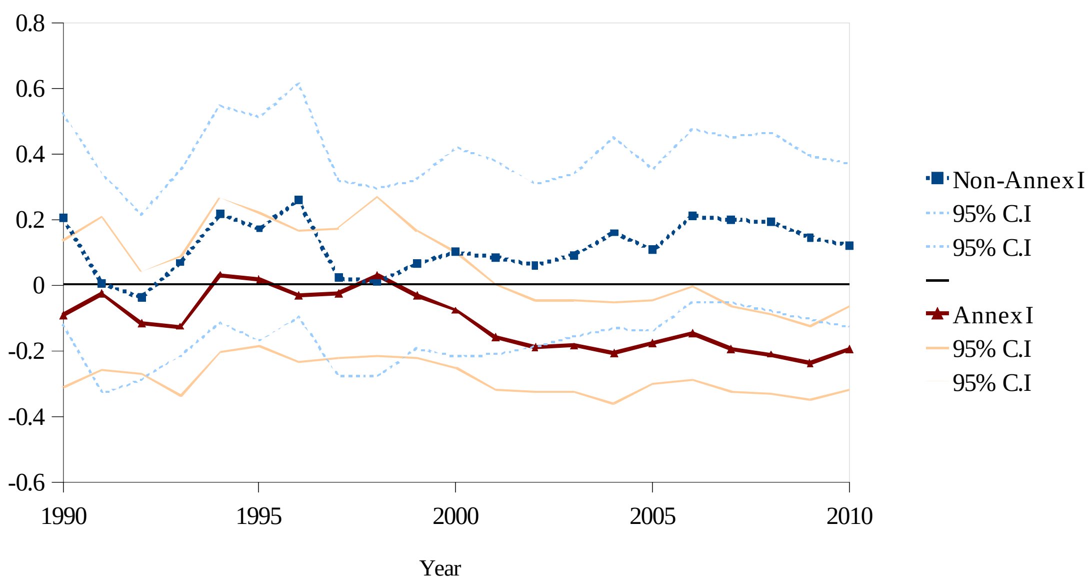

Figure 8: Coefficient on Emission Interaction for Annex I Countries

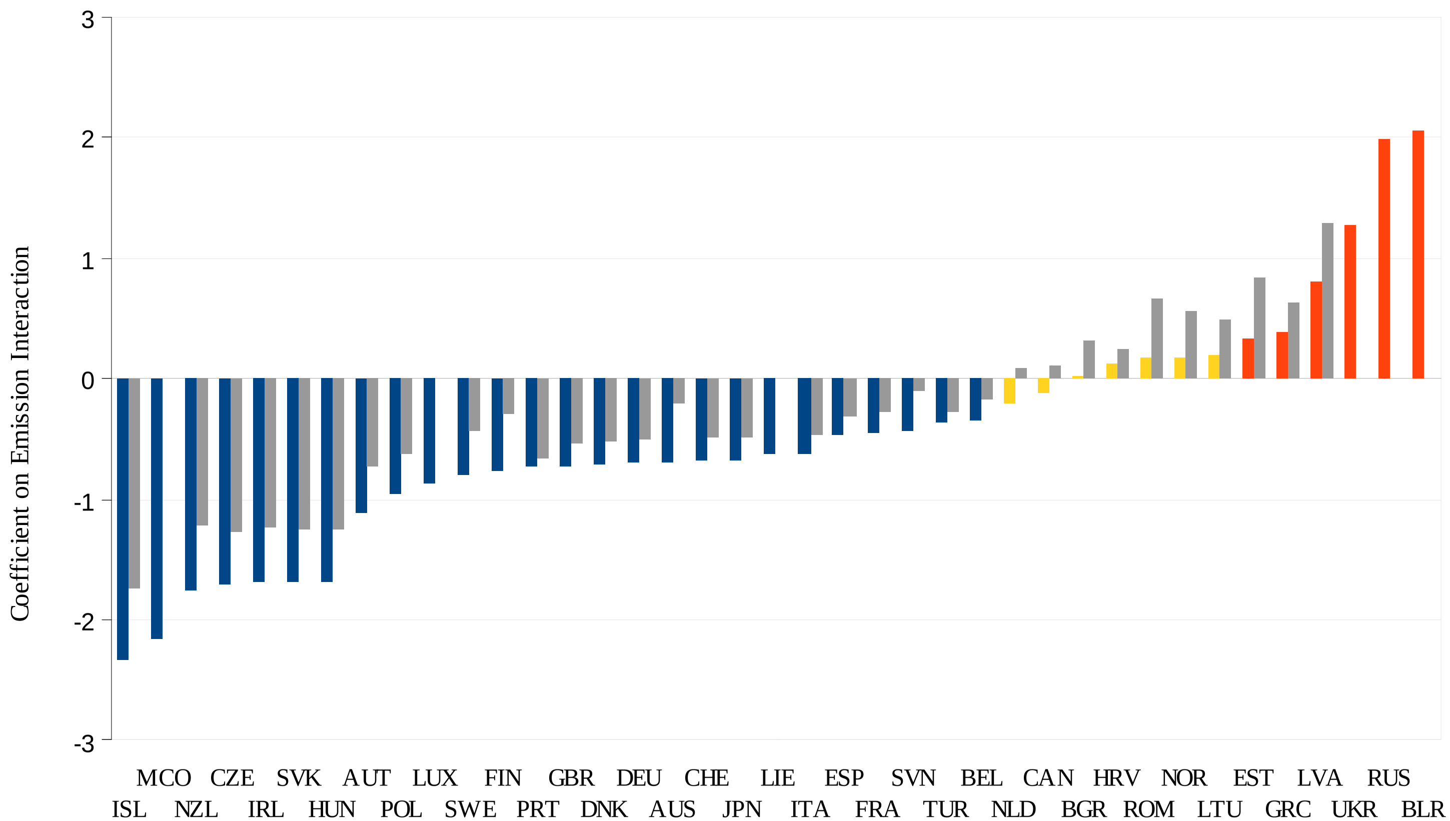

Table 1: Annex I Parties to UNFCCC and Kyoto Commitment

Party	Date of Ratification	Target *a* Ax.B	Target *a* Art.4*b*	Base *c* Level	Δ *d* 90-08	Party	Date of Ratification	Target Ax.B *a*	Base *c* Level	Δ *d* 90-08
European U. *b*	May 2002	-8	-8		-11.3	Croatia*	May 2007	-5		-0.9
Austria	May 2002	-8	-13	0.4	10.8	Czech*	Nov 2001	-8	1.2	-27.5
Belgium	May 2002	-8	-7.5	0.8	-7.1	Estonia*	Oct 2002	-8	0.3	-50.4
Denmark	May 2002	-8	-21	0.4	-7.1	Hungary*a	Aug 2002	-6	0.5	-36.1
Finland	May 2002	-8	0	0.4	-0.2	Iceland	May 2002	10	0.0	42.9
France	May 2002	-8	0	2.7	-6.1	Japan	Jun 2002	-6	8.5	1.0
Germany	May 2002	-8	-21	7.4	-22.2	Latvia*	Jul 2002	-8	0.2	-55.6
Ireland	May 2002	-8	13	0.2	23.0	Liechtenstein	Dec 2004	-8	0.0	14.7
Italy	May 2002	-8	-6.5	3.1	4.7	Lithuania*	Jan 2003	-8		-51.1
Greece	May 2002	-8	25	0.6	23.1	Monaco	Feb 2006	-8	0.0	-11.4
Luxembourg	May 2002	-8	-28	0.1	-4.8	New Zealand	Dec 2002	0	0.2	22.7
Netherlands	May 2002	-8	-6	1.2	-2.4	Norway	May 2002	1	0.3	8.0
Portugal	May 2002	-8	27	0.3	32.2	Poland*	May 2002	-6	3.0	-29.9
Spain	May 2002	-8	15	1.9	42.3	Romania*	Mar 2001	-8	1.2	-46.9
Sweden	May 2002	-8	4	0.4	-11.7	Russia*	Nov 2004	0	17.4	-32.9
U.K.	May 2002	-8	-12.5	4.3	-18.5	Slovakia*	May 2002	-8	0.4	-33.9
Australia	Dec 2007	8		2.1	31.4	Slovenia*	Aug 2002	-8		5.2
Belarus*#	Aug 2005	-8			-35.1	Switzerland	Jul 2003	-8	0.3	0.5
Bulgaria*	Aug 2002	-8		0.6	-41.9	Ukraine*	Apr 2004	0		-53.9
Canada	Dec 2002	-6		3.3	24.1	U.S^		-7	36.1	13.3

a The column “Ax.B” reports emission reduction/limitation target, as a percentage change of base year level, specified in Annex B to the Kyoto Protocol. b Fifteen member States of the European Union agreed to meet their targets jointly in accordance with Article 4, paragraph 1. The column "Art.4" reports their respective targets. c This column reports baseline year emission levels as a percentage of all Annex I countries. d This column reports changes in total CO_2 equivalent GHG emissions without land use, land-use change and forestry (LULUCF).

* 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 emission reduction commitment of 92 per cent) has not yet entered into force. ^The U.S. is not a party to the Kyoto Protocol.

Note: Malta and Turkey are now Annex I members to the UNFCCC, however, they do not have commitments under the Kyoto Protocol.

Table 2: Correlation Between Output and Value Added Based Intensities

	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

$\mathrm{s}^{\mathrm{k}}_{\mathrm{E,T}}$, measures total emission per output, $\mathrm{s}^{\mathrm{k}}_{\mathrm{E,D}}$ measures direct emission per value added. Units are in metric tons of CO_2 per \$1000 in constant 2000 dollars.

Table 3: Correlations of 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

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

Table 4: The Most and the Least Emission Intensive Industries

Most Intensive	Intensities		Least Intensive	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	Computer terminals	.33	.15

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

Table 5: Climate Policy and Comparative Advantage in Emission Intensive Goods

Dependent Variable	All Industries	Manufacturing		
log imports	(1)	(2)	(3)	(4)
emission intensity	-.469***	-.425***	-.445***	-.292**
× Annex I status	(.135)	(.133)	(.145)	(133)
capital intensity				.005
× capital-labor ratio				(.059)
skill intensity				.381***
× year of schooling				(.085)
intensity measure	output	output	VA	VA
exporter fixed effect	Yes	Yes	Yes	Yes
industry fixed effect	Yes	Yes	Yes	Yes
Observations	18571	17214	17214	13667

Robust standard errors in brackets. *** indicates significance at 0.01 level, ** at 0.05 level, * at 0.1 level.

Table 6: Climate Change Policy and Comparative Advantage: Robustness

Dependent Variable	All Industries				
log imports	(1)	(2)	(3)	(4)	(5)
emission intensity					
× Annex I status	-.469***	-.529***	-.361**	-.349*	.053
	(.135)	(.171)	(.145)	(.199)	(.180)
× emission per capita		.138			
		(.154)			
× emission per GDP			.281**		
			(.120)		
× income per capita				-.142	
				(.158)	
× env. regulations					-.368***
					(.085)
exporter fixed effect	Yes	Yes	Yes	Yes	Yes
industry fixed effect	Yes	Yes	Yes	Yes	Yes
Observations	18571	17359	17359	17367	17367

Robust standard errors in brackets. *** indicates significance at 0.01 level, ** at 0.05 level, * at 0.1 level.

Table 7: Kyoto Ratification and Comparative Advantage

Dependent Variable	All industries		Manufacturing		
log imports	(1)	(2)	(3)	(4)	(5)
emission intensity	-.455***	-.228***	-.438***	-.203***	-.151**
× Annex I ratification	(.122)	(.071)	(.125)	(.069)	(.062)
emission intensity		-.246*		-.254*	-.097
× Annex I status		(.142)		(.142)	(.139)
capital share					.002
× capital endowment					(.057)
skill share					.456***
× skill endowment					(.092)
exporter-year fixed effect	Yes	Yes	Yes	Yes	Yes
industry-year fixed effect	Yes	Yes	Yes	Yes	Yes
Observations	354533	353739	325686	324937	265011

Robust standard errors in brackets. *** indicates significance at 0.01 level, ** at 0.05 level, * at 0.1 level.

Table 8: Changes in Trade Flows

Dependent Variable:	2000-2007		1992-1999	
diff. log imports	(1)	(2)	(3)	(4)
emission intensity	-.197**	-.221**	-.003	-.003
× Annex-I Status	(.086)	(.094)	(.048)	(.052)
capital intensity		-.058**		-.004
× capital-labor ratio		(.028)		(.020)
skill intensity		-.019		-.038
× year of schooling		(.038)		(.029)
exporter fixed effect	Yes	Yes	Yes	Yes
industry fixed effect	Yes	Yes	Yes	Yes
Observations	13060	11295	12323	10747

Robust standard errors in brackets. *** indicates significance at 0.01 level, ** at 0.05 level, * at 0.1 level.