

Trade composition and carbon control efforts: carbon leakage revisited based on the carbon terms of trade of China

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Abstract

This paper investigates the changing patterns of the carbon terms of trade (CTT) of China with its 55 trade partners during 1996-2009. Using a Gravity-style model, we analyze how China's CTT was affected by the general environmental regulatory strictness of its trade partners and distinguish the potential difference in this impact between Annex I and non-Annex I countries. Among the Annex I countries, we focus on those that committed to binding carbon reduction targets under the Kyoto Protocol and further distinguish those that actually achieved the target (whether in whole or part). Our results confirm that, all else being equal, the environmental regulation in an Annex I country has a significantly higher impact on China's CTT. This conclusion is supported by majority of the 26 environmental regulatory stringency measurements previously used in the literature, and robust after considering the potential endogeneity of the decision to commit to the Kyoto targets.

Keywords: carbon leakage, carbon terms of trade, Annex I vs. non-Annex I, Kyoto carbon target, carbon reduction commitment, Gravity model.

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1. Introduction

China is without any doubt the developing country that has received the most attention in the recent hot debate on climate change and adaptation policies. In 2006, China overtook the US and became the world's biggest CO₂ emitter. By 2009, the historical accumulation of China's CO₂ emissions reached 9% of the world total, making it the world's 3rd biggest contributor to CO₂ content in the atmosphere since 1850, behind the US and the EU (Lin and Xu, 2014). In 2013, the annual CO₂ emissions of China reached 8.97 Gt, accounting for 28% of the world's total emissions (IEA, 2015). In October 2014, a press release announced that China overtook the EU in per capita CO₂ emissions².

The potentially important contribution of international trade to China's CO₂ emissions expansion in the last decades has been extensively documented in the literature related to balance of emissions embodied in trade (BEET). Shui and Harriss (2006), focusing on the bilateral trade between the US and China, concluded that approximately 7%-14% of China's current CO₂ emissions are the result of producing exports for US consumers and that US CO₂ emissions would increase from 3% to 6% if the goods imported from China were produced domestically in the US. Weber and Matthews (2007) also underlined the very large proportion of carbon embodied in US imports from China and especially the rapid increase of this proportion. Li and Hewitt (2008) estimated the amount of carbon dioxide embodied in bilateral trade between the UK and China in 2004 and found that the UK reduced its CO₂ emissions by approximately 11% through trade with China. Reinvang and Peters (2008) found that China is the developing country where Norway's carbon footprint is largest and increasing most rapidly, almost tripling from 2.4 Mt in 2001 to 6.8 Mt in 2006, and that on average every Norwegian causes emissions of 1.5 tonnes of CO₂ in China. Liu et al. (2010) calculated the carbon embodied in the bilateral trade between China and Japan, and found that China was a net exporter of CO₂ to Japan during the whole period between 1990 and 2000. Wagner (2010), based on the energy content of world trade, indicated that the disparities between the energy content of consumption and production in the US can be explained in "large portion" by the recent, steadily increasing US trade deficit with China. Atkinson et al. (2011) calculated the trade in "virtual carbon" via a MRIO (Multi-Region Input-Output) approach and found China to be the source of 36% of virtual carbon exports, of which exports to the US account for 21%.

The large surplus in China's BEET, however, cannot be considered evidence of carbon leakage. This is because the fundamental focus in the debate about "carbon leakage" is the *causality* between the set-up of more restrictive carbon mitigation objectives and the loss of "competitiveness" in the developed countries (Reinaud, 2008). This has been one of the principal concerns that prevented the United States from adopting the carbon control target suggested by the Kyoto Protocol (Parker and Blodgett, 2008)³ and pushed the European

² <http://www.bbc.com/news/science-environment-29239194> (consulted Oct 1st 2014)

³ Their reasoning is that industries that must control their emissions will find their feedstock or energy bills rising because of costs passed through by suppliers. Such an increase in production cost will make firms less competitive and cause them to lose global market share (and jobs) to competitors in countries lacking comparable carbon policies.

Union to propose a list of 164 sectors that might suffer a material competitive disadvantage against competitors located in areas outside of the EU and to provide them with supplementary allowances free of charge to ensure their gradual adaptation to the carbon reduction target (European Union, 2010)⁴.

The BEET-related studies, focusing on the *total* emissions embodied in trade volumes between countries, have less information to provide on this aspect. Previous studies already discussed the potentially substantial sensitivity of BEET to trade imbalances (Staubmann, 2003) and to the technological gap between trade partners (Grether and Mathys, 2013). Because of China's large trade surplus with most of the developed countries and the dominance of coal in its energy consumption structure (over 75%), we suspect the surplus of carbon calculated from BEET risks exaggerating the actual carbon emission loads displaced from the Annex I countries to China. He and Jacquemin (2015) calculated the BEET between China and France; they found that the real transfer of carbon load from France to China in 2005 was about 1.06% of the total BEET and that the remaining 98.94% of BEET was explained by the Sino-French technological gap, measured by the difference in carbon emission intensity between the two countries.

In addition, the increase in BEET in China may also be explained by some other factors. For example, as a natural process of industrialization, China's comparative advantage may also diverge gradually into more carbon-intensive sectors, even without the influence of competitiveness gained due to trade with countries that have tightened their environmental regulations in order to enforce the Kyoto Protocol. Another example is that, with economic growth, a wealthier Chinese population may also consume more industrialized goods (durable goods, for example), which can also lead to expansion of carbon-intensive sectors in China's industrial structure.

In this paper, we therefore propose to re-investigate the "carbon leakage" phenomenon by analyzing the evolution of China's "trade composition" in 28 manufacturing sectors with its 55 trade partners (32 Annex I countries and 23 developing countries) for the period 1996-2009.⁵ The question that we try to answer is whether the proportion of carbon-intensive products in China's "trade composition" increased due to the effects of climate policies on its trade partners. More precisely, we study both the choice of Annex I countries to commit to binding GHG emission reduction targets under the Kyoto Protocol and their actual attainment of these targets, whether in whole or part. Although the United States is an Annex I country and a major trading partner of China, it does not belong to the list of Annex I countries studied in our paper because of the decision of the United States not to commit to binding targets under the Kyoto Protocol. We therefore regrouped the US with the non-annex I countries.

⁴ With the goal of controlling the risk of carbon leakage under the revised EU ETS, which applied at the beginning of 2013, any installations in the sectors that are deemed to be exposed to a risk of carbon leakage will receive up to 100% of the allowances free of charge at the benchmark level, and the sectors that are not deemed at risk of carbon leakage will instead receive 80% of their allowances free of charge at the benchmark level. This proportion will decrease to 30% in 2020 and 0% in 2027, and the list of sectors will be revised every five years.

⁵ A detailed list of the countries is provided in Appendix 4. For the period of our study, these 55 countries' trade with China constituted 88%⁵ of China's total trade with the world.

Following the “pollution terms of trade” (PTT) developed by Antweiler (1996), we construct “carbon terms of trade” (CTT) to measure the “trade composition” of China with each of its trade partners. We simply take the ratio of average pollution content per dollar of exports over the average pollution content avoided per dollar of imports; both are calculated based on China’s sector-level carbon intensity. The main advantage of the CTT/PTT index is its capacity to abstract the bias caused by the trade imbalance and the carbon intensity gap between China and its trade partners.

The contribution of our paper to the related literature is fourfold. Firstly, although numerous papers have studied the pollution haven hypothesis by analyzing how a country’s environmental regulatory strictness affects its trade composition, there are still very few papers using this strategy to study the carbon leakage phenomenon. The only exception is Aichele and Felbermayr (2015), which uses a country’s inclusion in the Kyoto Protocol to directly explain the carbon content of sector-level bilateral trade flows. Our paper distinguishes itself from the previous work by explicitly separating the impact on trade composition of the general level of environmental regulatory stringency (26 measurements previously used in the literature) from the impact of the Kyoto-related carbon control policy. Moreover, for the Kyoto-related carbon policy, we consider not only the acceptance of binding targets under the Kyoto Protocol by Annex I countries (as in Aichele and Felbermayr, 2015), but also a country’s actual attainment of all or part of the Kyoto carbon control target as of 2012, with the aim of providing a precise measurement of different countries’ Kyoto-related carbon policy strictness.

Secondly, by using the PTT/CTT as the key indicator, our paper investigates the carbon leakage phenomenon directly via the channel of “competitiveness leakage” (Reinaud, 2008) by focusing solely on the composition effect of trade. This can be compared to the findings of the existing input-output studies, whose conclusions are generally based on the total scale of the balance of carbon incorporated in trade, very often a combined result of scale, composition and technical effects. Our strategy also presents advantages with respect to the papers focusing on the impact on trade of environmental regulation of polluting industries, since our study provides a more comprehensive view of the problem and avoids the potential bias due to researchers’ discretion in sector selection.

Thirdly, most of the existing pollution haven hypothesis studies use trade data from the developed countries, such as the US (Kahn, 2003; Ederington et al, 2005; Levinson and Taylor, 2008; Broner et al. 2012); the EU (Cave and Blomquist, 2008); and the Annex I countries (Tobey, 1990; Costantini and Crespi, 2008). Our paper focuses on the bilateral trade of China, with the aim of providing another look at this phenomenon from the point of view of this important developing country, which for several decades has played the role of the “world’s factory” and has been involved in international trade with almost all countries of the world, in most manufacturing sectors. Investigating the evidence of carbon leakage has significant implications for China’s own climate policy. If the carbon leakage phenomenon holds in China’s international trade, the increasing tendency of China’s exports to concentrate in carbon-intensive sectors may cast a shadow on China’s recent ambitious climate policy, including the intention to “achieve the peaking of CO₂ emissions

around 2030 and to make best efforts to peak early” (U.S.-China Joint Announcement on Climate Change, November 2014) and the intention to reduce “its carbon intensity by 60 to 65 percent of 2005 levels by 2030” announced by Prime Minister Keqiang Li in June 2015.

Finally, although our analysis focuses on China, given the deep and wide integration of China’s economy with most of the countries in the world, we believe our findings can also provide interesting reflections about the status of “carbon leakage” on a global level. We also have something to say about the potential efficiency gains of the just-adopted Paris agreement, which presents a new vision about the role of developing and developed countries in the global collaboration for climate change mitigation and adaptation.

The rest of the paper is organized as follows. Section 2 introduces the construction of the indicator PTT, which can be considered a measurement of trade comparative advantage in terms of environmental performance. The evolution of the PTT for China’s total international trade with the 55 trade partners, more precisely the carbon terms of trade (CTT), is reported in Section 3. Section 4 presents the empirical models, in which we distinguish general environmental regulations from specific carbon target policy. The results of this analysis are reported in Section 5. In Section 6, we re-test the robustness of our findings with 25 other measurements of environmental regulatory strictness previously used in the related literature. Finally, we discuss and conclude the paper in Section 7.

2. Measurement of trade performance: Pollution Terms of Trade

Our paper enters the rich literature studying the role of environmental regulation on trade performance. A recent survey (Decgezekeprêtre and Sato 2014) has provided a good review about the development of the issue. The main analytical strategy of this literature is to explain the relationship between trade flows, or the emissions embodied in the trade flow, with the associated level of environmental regulatory stringency. For the developed countries, if an increase in the stringency of environmental regulation leads to a decrease of its trade performance, especially for the pollution-intensive sectors/products, we can consider this evidence of the pollution haven hypothesis.

Most of the studies based on data from developed countries have used sector-level imports (exports) or net imports (exports) to measure trade performance. These include Ederington and Minier (2003); Ederington et al. (2005); Levinson and Taylor (2006); Constantini and Crespi (2008); Cave and Blomquist (2008); Cole et al. (2010); and Aichele and Felbermayr (2015). As this trade performance measurement does not directly reveal the environmental aspects of trade, these authors have concentrated their analyses on either environmentally relevant sectors/products (as in Costantini and Crespi (2008), who focus on energy technology exports of 20 industrialised countries) or heavily polluting and less footloose sectors, whose competitiveness was found to be affected more significantly by stricter environmental regulation (see Ederington et al. (2005) and Cave and Blomquist (2008)) . One shortcoming of this type of study, when applied to developing countries such as China, is its potential bias related to scale effects. As an industrialising country, China’s imports or exports may increase simply due to proportional expansion of its industrial production

and/or its domestic demand. Very often, such changes will happen in parallel with China's income growth, which, in its turn, also pushes environmental regulation to improve. Simply regressing the variation of export/import volumes on environmental regulation can therefore bias the estimation.

This problem can be partially avoided by using sector-level or country-level comparative advantage measurement. The examples are Cole et al. (2005), Broner et al. (2012) and He and Fu (2014), which have used the revealed comparative advantage index (Balassa, 1965, 1979, 1986), more specifically the relative import shares of country j in a specific sector s from country i , or, as in Kahn (2003), the ratio of imports over total domestic consumption.

The concept of Pollution Terms of Trade (PTT) was first proposed by Antweiler (1996) to measure "(whether) countries gain or lose environmentally from engaging in international trade". For a given country, China, for example, its PTT with a trade partner f at time t can be written as in Equation (1):

$$PTT_t^f = \frac{\sum_{i=1}^N \left(e_{it}^k \frac{x_{it}^f}{\sum_{j=1}^N x_{jt}^f} \right)}{\sum_{i=1}^N \left(e_{it}^k \frac{m_{it}^f}{\sum_{j=1}^N m_{jt}^f} \right)} \quad (1)$$

where the index i, j signifies the sectors; the superscript f is the trade partner; t is the time; e is the sector-level pollution intensity of the given country (here, China);⁶ and x and m represent exports and imports, respectively. In this equation, the numerator can be considered the weighted average emission intensity of exports and the denominator is the weighted average emission intensity of imports. The PTT can therefore be interpreted as the ratio of the pollution content of one dollar's worth of exports relative to the pollution content of one dollar's worth of imports. A country can be considered as the loser in the environmental terms of trade whenever its $PTT_t^f > 1$, which signifies that, for each dollar of trade with a country f , the pollution caused by the production of exports is greater than the pollution avoided by imports.

The PTT shares same concept as the embodied effluent trade ratio (EETR), which was proposed by Lee and Roland-Holst (1997). The EETR can be written as:

⁶ More details about the calculation of sector-level carbon emission intensity are given in Appendix 1.

$$EETR_t^f = \frac{\frac{\sum_{i=1}^N \left(e_{it}^k \frac{x_{it}^f}{\sum_{j=1}^N x_{jt}^f} \right)}{\sum_{i=1}^N \left(e_{it}^k \frac{Q_{it}^f}{\sum_{j=1}^N Q_{jt}^f} \right)}}{\frac{\sum_{i=1}^N \left(e_{it}^k \frac{m_{it}^f}{\sum_{j=1}^N m_{jt}^f} \right)}{\sum_{i=1}^N \left(e_{it}^k \frac{Q_{it}^f}{\sum_{j=1}^N Q_{jt}^f} \right)}} \quad (2).$$

where both the weighted average emission intensity of exports and imports are normalised by the weighted average emission intensity of production Q of the country. Because the reference base for the normalisation is the same in the numerator and denominator of the ratio, we know that $EETR_t^f = PTT_t^f$. Lee and Roland-Holst (1997) use EETR to compare the pollution embodied in exports and imports. Their paper approaches the link between the PTT and the idea of comparative advantage and argues that “as countries impose different environmental costs on pollution, then the ability to pollute becomes a source of comparative advantage” [page 67]. They therefore expect relatively higher EETR/PTT for countries with lower environmental standards. In this way, Lee and Roland-Holst (1997) considered EETR/PPT as a measurement of cross-sector comparative advantage focusing on environmental performance. Taking China as the given country, if its $EETR_t^f = PTT_t^f > 1$, China’s comparative advantage with respect to country f can then be considered to lie in relatively more polluting sectors.

As a measurement of pollution-related comparative advantage, the PTT provides several advantages compared to the simple (net) imports/exports. First of all, using the pollution content of trade provides us with a more direct way to interpret the potential relationship between environmental regulatory stringency and environmental-related trade performance. Secondly, by measuring the average intensity, and, in particular, focusing on the emissions from each unit of production, the PTT can avoid the potential bias related to “the balance of payment effects,” which makes the “long-run cross-country comparison unreliable” (Antweiler, 1996). The third advantage is specific to the case of China, whose international trade during the last three decades has benefited heavily from the processing trade, where imported components/pieces are assembled and re-exported to the rest of the world. The PTT, as a ratio of emissions per dollar of exports over emissions per dollar of imports, actually provides a partial control of this phenomenon, as the inflow (import) of intermediate inputs and the outflow (export) of final products appear as the denominator and numerator respectively. Fourth, our paper uses sector-level emission intensity of China in calculating emissions caused by exports and avoided by imports. In such a situation, we can further isolate our results from the potential divergence in technological progress between countries.

3. Evolution of China’s CTT

The data used to calculate China’s carbon terms of trade are from the Chelem International Trade Database (bilateral trade data), Chinese Statistics Yearbook (sector-level production

data) and Chinese Energy Statistics Yearbook (sector-level energy consumption data, which are used to calculate the sector-level carbon emission intensity). The details of how the sector-level carbon emission intensities are calculated are provided in Appendix 1.

Figure 1 reports the evolution of the CTT for the total trade of China with its 55 trade partners during 1996-2009. As illustrated in Figure 1, during the entire period of our study, the value of the CTT stayed steadily below one, which means that China's exports were less carbon intensive than its imports. While some relatively large fluctuations were observed in 1998 (Asian financial crisis) and in 2001 (recession in the US and collapse of the Dot-com bubble), the CTT experienced an overall increasing tendency in 1996-2009, with the value varying from 0.47 in 1996 to 0.59 in 2007. This trend continued until the beginning of the subprime crisis and world recession in Fall 2008, when there was a slight increase in the carbon terms of trade.

(Please insert Figure 1 about here)

The fact that China's total CTT was less than one seems to contradict the large surplus of the balance of carbon embodied in trade that has been frequently reported by previous input-output analyses. This contradiction may be addressed by considering that countries of different income levels have exerted different levels of effort toward achieving the Kyoto targets. In Figure 2, therefore, we report China's CTT for its trade with countries belonging to two groups: Annex I countries that committed to binding targets under Kyoto ("Kyoto-committed Annex I countries") and non-Annex I countries and the US. The CTT reported in Figure 2 reports similar findings as in Figure 1. With values of CTT lower than one in all years in both panels of Figure 2, this reveals that, if we concentrate on each dollar's trade exchange, China in fact benefits environmentally from its international trade in most of the years. Contrary to our expectation, during the period of our study, with annual CTT staying between 0.45-0.6, China's environmental gains from trade with Kyoto-committed Annex I countries were actually higher than those from trade with the non-Annex I countries and the US (vs. CTT varying between 0.55-0.8).

This gain, however, seems to be decreasing since 1996. This is true for trade with both Kyoto-committed Annex I countries and non-Annex I countries, where the CTT maintains a slow but persistent increasing trend, from 0.445 in 1996 to 0.618 in 2007 for Kyoto-committed Annex I countries and from 0.56 in 1996 to 0.751 in 2007 for non-Annex I countries and the US, prior to the 2008 subprime financial crisis.

(Please insert Figure 2 about here)

4. Empirical models

Although the dynamics of CTT with Kyoto-committed Annex I countries seems to predict an increasing tendency of China's comparative advantage in carbon-intensive sectors, this is not yet direct evidence that this economy is gaining a comparative advantage in carbon-intensive sectors due to the carbon control policies of its trade partners.

To investigate the impact of carbon emission control strictness on trade comparative advantage measured by the CTT, we employ the empirical specification in Equation (3):

$$\ln CTT_{it} = \alpha_i + \gamma_t + \beta_1 \Delta KL_{it} + \beta_2 \Delta SK_{it} + \beta_3 \Delta HK_{it} + \beta_4 \Delta FUEL_{it} + \beta_5 \Delta MIN_{it} + \beta_6 \Delta INNO_{it} + \beta_7 \Delta REG_{it} + \beta_8 \Delta REG_{it} \times Kyoto\ related + \epsilon_{it} \quad (3)$$

where CTT_{it} is the carbon terms of trade measuring the comparative advantage of China relative to country i at time t ; and α_i and γ_t are fixed country and year effects. We next discuss the other variables in detail.

To capture the impact of factor endowments on comparative advantages, $\Delta KL_{it} = \ln(KL_{it}/KL_{ct})$, $\Delta SK_{it} = \ln(SK_{it}/SK_{ct})$ and $\Delta HK_{it} = \ln(HK_{it}/HK_{ct})$ measure the differences in three dimensions of factor endowment between country i and China at period t , which are respectively capital-labor ratio, skilled-labor ratio ((skilled+basic skills)/unskilled) and highly-skilled-labor ratio (skilled/basic skilled). Following the assumption of Antweiler et al. (2001) that capital-intensive sectors are more pollution intensive, we expect negative coefficients for β_1 because the higher is the capital-labor ratio of trade partner country i with respect to China, the lower should be China's possibility of gaining comparative advantage in carbon-intensive sectors in bilateral trade with this country. As there is not a clear relationship between the skilled labor ratio and pollution intensity, we will leave our estimation to determine the sign of the coefficients for the variables ΔSK_{it} and ΔHK_{it} . $\Delta MIN_{it} = \ln(MIN_{it}/MIN_{ct})$ and $\Delta FUEL_{it} = \ln(FUEL_{it}/FUEL_{ct})$ capture the differences in mineral and fossil fuel abundance of country i compared to China; these two variables are included in our model because there is a close correlation between carbon emission and mineral/fossil fuel intensity. We expect negative coefficients for these two variables: the higher is the mineral and fuel intensity in a country i with respect to China, the lower will be the possibility of China gaining comparative advantages in carbon-intensive sectors. $\Delta INNO_{it} = \ln(INNO_{it}/INNO_{ct})$ measures the level of research and development of country i with respect to China. The coefficient associated with this variable can be either positive or negative. If the technical progress is biased toward carbon-intensive sectors, a country i with a higher R&D capacity may reduce the CTT of China's bilateral trade. On the contrary, if the technical progress is biased toward less carbon-intensive sectors, trade with a country with higher R&D can cause China to increase its CTT.

Our central variables are the two variables related to $\Delta REG_{it} = \ln(REG_{it}/REG_{ct})$, which measures the difference in general environmental regulatory strictness between country i and China at period t . If the carbon leakage phenomenon results from a general difference in environmental regulatory strictness between countries, we should expect the coefficient β_7 to be positive, because the more stringent is the environmental regulation in country i compared to China, the greater will be the chance for China to gain comparative advantage in carbon-intensive sectors through its bilateral trade with this country. As the first step, we used per capita GDP as a proxy for environmental regulatory stringency. Per capita GDP is one of the earliest proxies for environmental regulation in related studies (Panayotou, 1997, Dean, 1998; Antweiler et al., 2001, etc.). The underlying belief is that

environmental quality is a normal good, whose demand increases with income; therefore, in general, richer countries should have stricter environmental regulation.

The general level of environmental regulatory stringency, however, may not exactly coincide with the carbon emission control efforts in different countries. There are two reasons for this. First, due to the nature of carbon emissions as a global negative externality, polluters are insufficiently motivated to control emissions because the negative effects are felt elsewhere. Second, most of the carbon emission reduction realized in the world until now has been due to the Kyoto Protocol, which is an international process that has only a limited connection to the general level of regulatory strictness in individual countries. With the aims of further precision, we focus on carbon-related regulatory stringency, by using cross-terms between the general stringency and three Kyoto-related variables: 1) a dummy indicating whether or not trade partner f is an Annex I country that committed to binding targets under Kyoto (*AnnexI*) and 2) a dummy indicating whether or not trade partner f attained (at least partially) its carbon reduction target (*attainment*).⁷ We anticipate positive coefficients for these Kyoto-related cross terms, because, if carbon leakage holds, all else being equal, a Kyoto-committed Annex I country, particularly one that at least partially attained its target, should exert more impact on the CTT of China's bilateral trade.

Our empirical model is directly inspired by the gravity framework, originally used in bilateral trade flow determination studies (Tinbergen, 1962; van Beers and van den Bergh, 1997). For several years, the gravity equation has been employed in several studies on the effects of environmental regulation on trade flows. Good examples are Cole et al. (2005) and Broner et al. (2012); both used a similar framework to examine the comparative advantage of the US, either for different industrial sectors or with respect to different trade partners. Both papers used the *absolute value* of the physical and human capital intensity and environmental regulatory stringency of corresponding sectors/trade partners as determining variables in their gravity-style model. Our model is more similar to Grether et al. (2012), which tried to explain the determination of total and average pollution content of the imports of 48 countries during 1986-1988 with the *difference (or distance) between trade partners* in capital-labor ratio, skilled and high-skilled labor ratio, coal and oil abundance and environmental regulatory stringency.

5. Empirical results

Table 1 provides a detailed explanation and descriptive statistics of the data used in our gravity-style model. The detailed estimation results are given in Table 2. All the reported estimations control both year and trade-partner country fixed effects. The first column of Table 2, entitled Model (1), reports the estimation model including only the general regulation, ΔREG , which is proxied by the relative per capita GDP of the trade partner with respect to China. The further estimation of the model, including the cross-terms of ΔREG with one of the two Kyoto-related variables (*AnnexI* or *attainment*), are reported in the following columns entitled Model (2). We note that a large proportion of the Kyoto-

⁷ Detailed information about the countries belonging to the Annex I list and whether they agreed to be bound by the protocol is provided in Appendix 5.

committed Annex I countries that attained some or all of their carbon targets are Former Soviet Union (FSU) countries (see Appendix 5). We suspect that these countries have had fewer difficulties in attaining carbon reduction targets, because the severe economic downturn and the diversification of their previously highly-concentrated heavy industries after independence from the former Soviet Union in the 1990s may make carbon reduction an easier process. A similar concern was found in Almer and Winkler (2012). This is very different from the “carbon leakage” situation of the developed countries in the Kyoto-committed Annex I list. We therefore further separate the cross-term of ΔREG with Kyoto-related variables of the Kyoto-committed Annex I FSU countries from the Kyoto-committed Annex I countries which did not belong to the FSU (called OECD in the table), with the aim of capturing the potential difference between these two groups of countries (see the results in the columns entitled Model (3)).

The results from the different models reveal good coherence and stability. Table 2 reports significant negative coefficients for ΔSK (skilled-labor ratio), signifying that China exports fewer carbon-intensive goods to a partner country with a higher ΔSK ; on the contrary, the significant positive coefficients for ΔHK (high-skilled-labor ratio) reveal the tendency that a country with a higher ΔHK imports more carbon-intensive goods from China. The variables measuring the relative fuel and mineral abundance of a partner country report negative coefficients in most of the models; although not significant, they tend to confirm our anticipation that China’s exports to a trade partner rich in fossil fuel and mineral reserves are more concentrated in less carbon-intensive sectors, which predicts a lower CTT. The relative level of R&D (ΔINNO) reports significantly positive coefficients, which predict that China’s trade with a country of more advanced R&D leads to a higher CTT for China. This suggests that current R&D activity by trade partners happens more often in less carbon-intensive sectors.

The key variables of our study are the ΔREG and its cross-terms. First of all, in all columns, ΔREG has positive coefficients, although those in the last two columns are not statistically significant. This confirms our belief that China’s CTT is significantly higher in its trade with countries adopting stricter general environmental protection policies. However, as mentioned above, it is the significant positive coefficients of the cross-terms between ΔREG and Kyoto-related variables that can be considered direct evidence of carbon leakage. This is what we found in the columns entitled Model (2). The logic of the positive coefficient is simple: all else being equal, China’s CTT will be significantly higher for its trade with Kyoto-committed Annex I countries. Moreover, the positive and significant coefficients of interest are very stable over models using both qualitative dummies: whether a country signed the Kyoto Protocol as an Annex I (*Annex I*) country and whether a country attained its carbon control target (*attainment*). Further distinguishing the coefficients of the cross-terms between *FSU* countries and *OECD* countries reveals that the FSU countries that belong to Annex I contribute more heavily to the carbon leakage to China. Compared to the coefficients for the FSU counterparts, the smaller values for the coefficients of the cross-term $\Delta\text{REG}*\text{KP}*OECD$ signify, in general, a smaller but significant contribution of OECD Annex I countries than FSU countries to the carbon leaked to China via trade.

(Please insert Tables 1-2 about here)

Considering that the Kyoto Protocol is a voluntary international agreement, we have reason to expect a that country that has easier “decarbonisation” solutions (i.e., a country that depends less on fossil fuel) may have had more motivation to enter the Annex I list and to attain its carbon reduction target. A similar idea was discussed in Aichele and Felbermayr (2015): “emission projections could also drive commitment (reverse causation)”. If it is generally easier for the countries currently belonging to Annex I to achieve the required emission reduction targets, the estimated positive coefficients of the cross-terms with Kyoto-related variables might under-estimate the potential carbon leakage to China via its bilateral trade with these countries.

To avoid the potential influence of such reverse causation on our estimation results, we also used an instrumentation strategy to eliminate the “reverse causation” between the carbon control target and Kyoto commitments. We follow the instruments and derivations proposed in Aichele and Felbermayr (2015). More precisely, the key instrument is countries’ membership in the international criminal court (ICC) based in The Hague, Netherlands⁸, as the key instrument for Kyoto commitment. Aichele and Felbermayr (2015) argued that the ICC statutes were ratified around the same time as the Kyoto protocol; therefore, the time variation in the ICC membership dummy has the potential to correlate with the time variation in the Kyoto status variable. The idea behind this instrumentation strategy is that both treaties reflect a country’s preferences for international policy initiatives. Some countries are more willing than others to give up national sovereignty and subject themselves to an international organization. As in Aichele and Felbermayr (2015), we also used the spatial lag of the ICC as instruments, where the instrument dummies of different countries are weighted by distance between a Kyoto-committed Annex I country and its neighbors, whose influence naturally depends on the geographical distance between them.⁹ The estimation results with instrumentation strategies are reported in the columns entitled Model (3) of Table 2. One general finding is that, once we controlled for the potential endogeneity of the decision to accept the Kyoto Protocol, the value of the positive and significant coefficients for the cross-terms between ΔREG and Kyoto-related policies became larger and more significant. This can be considered evidence confirming our initial concerns about reverse causality, i.e., that Annex I countries having more ability to attain carbon reduction targets were more willing to accept binding carbon reduction targets. Another interesting finding is that, once the potential endogeneity is controlled, the difference in the coefficients for the cross-term $\Delta REG \times attainment$ between FSU and OECD becomes much smaller, signifying a smaller difference in their contribution to carbon leakage to China via trade.

As proposed by Lee and Roland-Holst (1992) (cf. Eq. 2), the CTT can be further defined using two components: the normalized indicators in its numerator and denominator as

⁸ The Rome Statute, Page 732 and Page 737.

⁹ One particularity of our model is that our endogenous variables are included in a cross-term with an environmental regulation variable. By assuming that the environmental regulation variable is exogenous, we use the cross-term between instrument variables and the environmental regulation variable as valid instruments to the cross-term between *annexI/attainment* and regulation.

weighted intensity of carbon embodied in export (ICEE) and weighted intensity of carbon embodied in import (ICEM). So, we have:

$$ICEE_t^f = \frac{\sum_{i=1}^N \left(e_{it}^k \frac{x_{it}^f}{\sum_{j=1}^N x_{jt}^f} \right)}{\sum_{i=1}^N \left(e_{it}^k \frac{Q_{it}^f}{\sum_{j=1}^N Q_{jt}^f} \right)} \quad (4)$$

$$ICEM_t^f = \frac{\sum_{i=1}^N \left(e_{it}^k \frac{m_{it}^f}{\sum_{j=1}^N m_{jt}^f} \right)}{\sum_{i=1}^N \left(e_{it}^k \frac{Q_{it}^f}{\sum_{j=1}^N Q_{jt}^f} \right)} \quad (5)$$

These two indicators provide a comparison of the trade structure (export or import) with respect to the domestic production structure, from the point of view of carbon intensity. An $ICEE_t^f > 1$ signifies that the structure of exporting is more concentrated in carbon-intensive sectors, relative to the overall production structure of the economy. By contrast, an $ICEM_t^f < 1$ signifies that the structure of importing is concentrated in less carbon-intensive sectors than the overall domestic production.

We use the same estimation function of Eq. (3) to investigate the impact of carbon emission control strictness on these two components of CTT. The results are reported in Table 3. Further decomposing the CTT into export and import carbon intensity reveals more details about the impact of relative environmental regulatory strictness on CTT. First, the coefficients for ΔREG report significant negative signs for both ICEE and ICEM. This means that, in general, China's trade with a country that has stricter environmental regulation tends to happen in less carbon-intensive sectors. Because the magnitudes of the negative coefficients are much larger for ΔREG in the ICEM determination function (about -0.9) than in the ICEE function (around -0.4), we can also deduce that, for a specific country, the strengthening of its environmental regulation relative to China leads to a larger reduction in the carbon intensity of China's imports from it (ICEM) than in the carbon intensity of China's exports to it (ICEE). Second, in the estimation results for ICEE, we obtain positive and significant coefficients for both cross-terms, $\Delta REG * KP * FSU$ and $\Delta REG * KP * OECD$, which means that China's exports with an Annex I trade partner, compared to China's trade with non-Annex I countries, are significantly more carbon-intensive, all else being equal. Finally, the results with import intensities reveal an interesting difference among the countries belonging to the Annex I list. If the estimates report that the carbon intensity of China's imports from the FSU Annex I countries are statistically indistinguishable from the intensity of China's imports from the other non-Annex I countries (cf. the insignificant coefficients for $\Delta REG * KP * FSU$), the significant negative coefficients for $\Delta REG * KP * OECD$ mean that China's imports from these OECD Kyoto-committed Annex I countries are significantly less carbon intensive.

(Please insert Table 3 about here)

Combining the estimation results for ICEE and ICEM, we can see that the higher CTT of China's trade with OECD Kyoto-committed Annex I countries is driven by two factors. On one hand, China's exports to these countries are significantly more carbon intensive. On the other hand, their exports to China (China's imports) are significantly less carbon intensive. Both aspects can be considered direct evidence for the carbon leakage phenomenon.

6. Robustness checks

As we can see, the supportive evidence for the carbon leakage phenomenon is essentially based on the sign of the coefficient of the cross-terms of the variables measuring the environmental regulatory stringency and the Kyoto-related variables (*AnnexI*, *Attainment*). The general environmental regulatory stringency was proxied by per capita GDP in the previous section. However, there is not yet a commonly accepted measure for the stringency of environmental regulation. A systematic literature review conducted by Brunel and Levinson (2013) listed several difficulties in measuring environmental regulation. The first is the multidimensionality of environmental regulation, which indicates that the environmental regulations in one country cannot easily be captured by one single measure of "stringency". Some authors have tried to answer this criticism by the strategy of "narrowing down" and proposing various alternative measures, but a related difficulty is the comparability between these measures. Others have tried to address this criticism by constructing "broad" composite indexes or proxies (Ben Kheder and Zugravu, 2012, among others); their principal difficulty is to choose a pertinent weighting system for indicators describing different aspects of environmental regulation. Based on 26 primary studies, Rezza (2014) conducted a meta-analysis with the aim of investigating whether the choice of different measures of environmental regulatory stringency can affect the probability that a study will confirm the Pollution Haven Hypothesis. They identified four categories of environmental regulation measures, including firms' pollution abatement spending, governments' environmental spending, pollution intensity, and an executive opinion survey, and found that different categories of regulatory stringency measurement do affect the probability of obtaining results favoring the PHH; the government's environmental spending, as a proxy for the stringency of environmental regulations, gives the highest probability.

A similar question is also valid in our study: is the supportive evidence for our carbon leakage hypothesis also dependent on the choice of environmental regulation measurements? To test the robustness of our findings, we compiled 25 other environmental regulatory measurements that have been used in related studies. Appendix 6 provides the details of the 25 environmental regulation measurements.¹⁰ We regroup these measures into four categories: emissions and energy use; pollution abatement and environmental

¹⁰ The number of environmental regulation measurements is closely dependent on data availability. We censored in total 55 measurements previously used in the literature and only 25 have been collected/compiled/updated for the 56 countries (55 countries+China) in our study.

protection; institutional indexes; and, finally, composite indexes. The expected signs for the coefficients related to the carbon leakage phenomenon are also given in the table.

The estimated coefficients for these 25 environmental regulation stringency measurements and their cross-terms with Kyoto-related variables are given in Table 4. The coefficients confirming the carbon leakage hypothesis are underlined in bold in the tables. To our satisfaction, we can see that the coefficients related to our hypothesis have the expected signs for the majority of the environmental regulatory stringency measurements, although the statistical significance is more variable. This is true for both estimations including *Attainment* and *Annex I*. Although the simple environmental regulatory stringency measurement does not always obtain the expected sign, in general, its cross-terms with Kyoto-related variables perform better, revealing coefficients confirming the carbon leakage phenomenon in most cases.

(Please insert Tables 4 about here)

We also consider the robustness of our results with respect to the use of the following different instrumentation strategies.

- 1) Using the spatial lag of the ICC decision with distance weighted by the size of the population as an instrument.
- 2) Using the spatial lag of the ICC decision with simple distance as an instrument, but following the limited information maximum likelihood (LIML) instead of IV to reduce possible bias due to weak instruments (Stock and Yogo, 2005).
- 3) Using lagged growth rate of gross domestic product as an instrument.
- 4) Using the spatial lag of the ICC decision with simple distance as an instrument, but following the Wooldridge two-step procedure and directly using the predicted % of the probability of being a Kyoto-committed Annex I country in the second-step estimation.
- 5) Using the spatial lag of the ICC decision with simple distance as an instrument, but following the Wooldridge two-step procedure and redefining the probability of being a Kyoto-committed Annex I country to 1 or 0 based on whether the predicted % of probability is larger or smaller than 0.5.

The detailed results of these different instrumentation strategies are reported in Tables 5-7. As we can see, except for the instrumentation strategy using lagged growth rate of gross domestic product, the other instruments/strategies are found to be efficient most of the time. They report relatively stable coefficients (at least for the traditional OECD countries), revealing the carbon leakage potential in trade with China.

(Please insert Tables 5-7 about here)

7. Conclusion and discussion

This paper investigates the changing patterns of the carbon terms of trade (CTT) in China's bilateral trade with 55 partner countries during the period 1996-2009. We analyze how this CTT variable was affected by variations in the general level of environmental regulatory strictness in trade partner countries. Particular attention is given to the difference in the reaction of China's CTT to trade with Annex I countries that committed to or attained the carbon reduction target imposed by the Kyoto Protocol, compared to that of non-Annex I countries and the US.

Our calculation of CTT reveals firstly that exports from China are relatively less carbon-intensive than imports to China ($CTT < 1$ for most of the time with most of the countries). However, the dynamic tendency seems to indicate an increasing trend of an environmental burden via international trade in China, which seems to confirm the possibility that China was receiving carbon "leaked" from its trade partners during the period, from both the Kyoto signatory Annex I countries and non-Annex I countries. To deepen our analysis, in a second step we carried out the estimations based on an empirical model directly inspired by the gravity framework, which explains the determination of CTT of China's trade with its 55 trade partners with its *differences with trade partners* in capital-labor ratio, skill and high-skilled labor ratio, coal and oil abundance and environmental regulatory stringency.

Our results confirm the existence of the carbon leakage phenomenon in China's trade with its trade partners. We found that the stricter is a country's environmental regulation, the higher will be China's CTT with the country. Moreover, we also found this positive relationship to be stronger for China's Annex I trade partners that committed to binding carbon reduction targets under the Kyoto Protocol and for the Annex I countries that attained (partially or fully) their carbon reduction target. While, as expected, the countries belonging to the former Soviet Union seem to cause more leakage, this does not change the carbon leakage situation of the Kyoto signatory OECD countries belonging to the Annex I list, whether or not they attained part of their carbon targets. Further distinguishing the export intensities from the import intensities reveals that greater strictness of general environmental regulation relative to that of China leads to a larger reduction in the carbon intensity of China's imports (ICEM) than in the carbon intensity of China's exports (ICEE). All of the Kyoto signatories tend to have more carbon-intensive exports from China than do the non-Annex I countries. We find evidence of lower carbon intensity for China's imports from Kyoto-committed OECD countries than from non-Annex I countries and Kyoto-committed FSU countries.

The validity of these conclusions confirming the carbon leakage phenomenon for the Kyoto-committed OECD countries holds after controlling for the trade partners' general environmental regulatory stringency, measured by 26 different indicators previously used in the related literature. This conclusion is not affected after considering the potential endogeneity of an Annex I country's decision commit to binding targets under the Kyoto Protocol and its actual attainment.

Although our paper is based on the experience of China's bilateral trade with its 55 trade partners, we believe it provides a general understanding about the potentially large impact of carbon leakage around the world, thanks to China's wide integration with the world

economy and its predominant role in world carbon emissions. As our study focuses on the carbon leakage associated with each dollar of exports relative to each dollar of imports, we can therefore expect that the absolute amount of carbon leakage to China will grow as China's economy grows. However, changes are to be expected as China's carbon efficiency catches up with its developed trade partners and as its balance of trade shifts to more importing.

The evidence of carbon leakage found in our study also provides important insights about future international cooperation in climate change mitigation. The just-adopted Paris agreement, by recognizing climate change as “an urgent and potentially irreversible threat to [...] the planet and thus requires the widest possible cooperation by *all countries...*”, presents a new vision about the role of developing and developed countries in their carbon control target choices. Instead of sticking to the “common but differentiate[d] responsibility” directly related to carbon reduction results, the new agreement urges all countries, no matter their development levels, to contribute jointly to the objective of keeping the rise of world temperatures below 2 degrees. If countries can cooperate to achieve the proposed nationally determined contributions, with the help of the financial resources provided to developing countries and technological development and transfer, such a new vision should be able to reduce the potential influence of the carbon leakage phenomenon via international trade.

References

- Aichele, R., & Felbermayr, G. (2015). Kyoto and Carbon Leakage: An Empirical Analysis of the Carbon Content of Bilateral Trade. *Review of Economics and Statistics*.
- Antweiler, W. (1996). The Pollution Terms of Trade. *Economic Systems Research*, 8(4), 361–366.
- Antweiler, W., Copeland, B. R., & Taylor, M. S. (2001). Is Free Trade Good for the Environment? *American Economic Review*, 91(4), 877-908.
- Atkinson, G., Hamilton, K., Ruta, G., & Van Der Mensbrugge, D. (2011). Trade in “virtual carbon”: Empirical results and implications for policy. *Global Environmental Change*, 21(2), 563–574.
- Balassa, B. (1965). Trade Liberalisation and “Revealed” Comparative Advantage. *The Manchester School*, 33(2), 99–123.
- Balassa, B. (1979). The Changing Pattern of Comparative Advantage in Manufactured Goods. *Review of Economics and Statistics*, 61(2), 259–266.
- Balassa, B., & Noland, M. (1989). "Revealed" Comparative Advantage in Japan and the United States. *Journal of International Economic Integration*, 8–22.
- Barro, R. J., & Lee, J. W. (2013). A new data set of educational attainment in the world, 1950–2010. *Journal of development economics*, 104, 184-198.
- Broner, F., Bustos, P., & Carvalho, V. M. (2012). Sources of Comparative Advantage in Polluting Industries. *National Bureau of Economic Research Working Paper Series*.
- Brunel, C., & Levinson, A. (2013). Measuring environmental regulatory stringency.
- Cagatay, S., & Mihci, H. (2003). Industrial pollution, environmental suffering and policy measures: An index of environmental sensitivity performance (IESP). *Journal of Environmental Assessment Policy and Management*, 5(02), 205-245.
- Cagatay, S., & Mihci, H. (2006). Degree of environmental stringency and the impact on trade patterns. *Journal of economic studies*, 33(1), 30-51.
- Cave, L. A., & Blomquist, G. C. (2008). Environmental policy in the European Union: Fostering the development of pollution havens? *Ecological Economics*, 65(2), 253–261.
- Clair, G., Gaulier, G., Mayer, T., & Zignago, S. (2004). Notes on CEPII's distances measures. *CEPII: Paris*.
- Cole, M. A. (2003). Development, trade, and the environment: how robust is the Environmental Kuznets Curve? *Environment and Development Economics*, 8(04), 557-580.
- Cole, M. A., & Elliott, R. J. (2003). Determining the trade–environment composition effect: the role of capital, labor and environmental regulations. *Journal of Environmental Economics and Management*, 46(3), 363-383.
- Cole, M. A., Elliott, R., & Okubo, T. (2010). Trade, environmental regulations and industrial mobility: An industry-level study of Japan. *Ecological Economics*, 69(2010), 1995–2002.
- Cole, M. A., Elliott, R., & Shimamoto, K. (2005). Why the grass is not always greener: the competing effects of environmental regulations and factor intensities on US specialization. *Ecological Economics*.
- Combes, J. L., Motel, P. C., & Kinda, S. R. (2014). Do Environmental Policies Hurt Trade Performance? (No. halshs-00939249).
- Core Writing Team, Pachauri, R.K. and Reisinger, A. (Eds.). (2008). Contribution of Working Groups I, II and III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. IPCC, Geneva, Switzerland. pp 104
- Costantini, V., & Crespi, F. (2008). Environmental regulation and the export dynamics of energy technologies. *Ecological Economics*, 66(2-3), 447–460.
- Damania, R., Fredriksson, P. G., & List, J. A. (2003). Trade liberalization, corruption, and environmental policy formation: theory and evidence. *Journal of environmental economics and management*, 46(3), 490-512.
- Dasgupta, S., Mody, A., Roy, S., & Wheeler, D. R. (1995). Environmental regulation and development: a cross-country empirical analysis.
- Dean, J. M. (2002). Does trade liberalization harm the environment? A new test. *Canadian Journal of Economics/Revue canadienne d'économique*, 35(4), 819-842.
- Ederington, J., & Minier, J. (2003). Is environmental policy a secondary trade barrier? An empirical analysis. *Canadian Journal of Economics/Revue Canadienne D'économique*, 36(1), 137–154.
- Ederington, J., Levinson, A., & Minier, J. (2005). Footloose and Pollution-Free. *Review of Economics and Statistics*, 87(1), 92–99.

- Eliste, P., & Fredriksson, P. G. (2002). Environmental regulations, transfers, and trade: Theory and evidence. *Journal of Environmental Economics and Management*, 43(2), 234-250.
- European Union (2010). COMMISSION DECISION of 24 December 2009: determining, pursuant to Directive 2003/87/EC of the European Parliament and of the Council, a list of sectors and subsectors which are deemed to be exposed to a significant risk of carbon leakage. (notified under document C(2009) 10251) (Text with EEA relevance): http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=uriserv:OJ.L_.2010.001.01.0010.01.ENG&toc=OJ:L:2010:001:TOC.
- Grether, J.-M., & Mathys, N. A. (2013). The pollution terms of trade and its five components. *Journal of Development Economics*, 100(1), 19–31.
- Grether, J.-M., Mathys, N. A., & de Melo, J. (2009). Global manufacturing SO₂ emissions: does trade matter? *Review of World Economics*, 145(4), 713–729.
- Grether, J.-M.; Mathys, N. and de Melo J. (2012). Unravelling the worldwide pollution haven effect, *The Journal of International Trade & Economic Development*, 21:1, 131-162, DOI: 10.1080/09638190903552040.
- Harris, M., Konya, L., & Matyas, L. (2002). Modelling the Impact of Environmental Regulations on Bilateral Trade Flows: OECD, 1990-1996. *The World Economy*, 25(3), 387-405.
- He, J., & Fu, J. (2014). Carbon leakage in China's manufacturing trade: An empirical analysis based on the carbon embodied in trade. *The Journal of International Trade & Economic Development*. <http://doi.org/10.1080/09638199.2012.713389>
- Javorcik, B. S., & Wei, S. J. (2004). Pollution havens and foreign direct investment: dirty secret or popular myth?. *Contributions in Economic Analysis & Policy*, 3(2).
- He, J., & Jacqueman, J., 2015. "La balance du carbone incorporé aux commerces bilatéraux entre la France et la Chine : Transferts de responsabilité ou nouvelles créations?," Working Papers P84, FERDI.
- IEA (2015). IEA statistics: Key trends in CO₂ emissions: excerpt from CO₂ emissions from Fuel Combustion (2015 edition). International Energy Agency.
- Johnstone, N., & Kalamova, M. (2010). Environmental policy characteristics and technological innovation. *Economia politica*, 27(2), 277-302.
- Johnstone, N., Haščič, I., & Popp, D. (2010). Renewable energy policies and technological innovation: evidence based on patent counts. *Environmental and Resource Economics*, 45(1), 133-155.
- Kahn, M. E. (2003). The geography of US pollution intensive trade: evidence from 1958 to 1994. *Regional Science and Urban Economics*, 33(4), 383-400.
- Kellenberg, D. K. (2009). An empirical investigation of the pollution haven effect with strategic environment and trade policy. *Journal of international economics*, 78(2), 242-255.
- Kheder, S. B., & Zugravu, N. (2010). The pollution haven hypothesis: a geographic economy model in a comparative study. Working Paper
- Kheder, S. B., & Zugravu, N. (2012). Environmental regulation and French firms location abroad: An economic geography model in an international comparative study. *Ecological Economics*, 77, 48-61.
- Lee, H., & Roland-Holst, D. (1997). The environment and welfare implications of trade and tax policy. *Journal of Development Economics*, 52(1), 65-82.
- Levinson, A., & Taylor, M. S. (2008). Unmasking The Pollution Haven Effect. *International Economic Review*, 49(1), 223–254. <http://doi.org/10.1111/j.1468-2354.2008.00478.x>
- Li, Y., & Hewitt, C. N. (2008). The effect of trade between China and the UK on national and global carbon dioxide emissions. *Energy Policy*, 36(6), 1907–1914.
- Lin, J. Y-F, J. Xu (2014). The Potential for Green Growth and Structural Transformation in China. *Oxford Review of Economic Policy* 30.3 (2014), 550-568.
- Liu, X., Ishikawa, M., Wang, C., Dong, Y., & Liu, W. (2010). Analyses of CO₂ emissions embodied in Japan–China trade. *Ecological Economics*, 38(3), 1510–1518.
- Panayotou, T. (1997). Demystifying the environmental Kuznets curve: turning a black box into a policy tool. *Environment and development economics*, 2(04), 465-484.
- Parker, L., & Blodgett, J. (2008). „Carbon leakage “and trade: issues and approaches. Congressional Research Service, 19.
- R. Straumann. (2003). Exporting pollution? Calculating the embodied emissions in trade for Norway. Reports 2003/17, Statistics Norway
- Reinaud, J. (2008). Issues behind competitiveness and carbon leakage. focus on heavy industrys. IEA Information Paper.

- Reinvang, R., & Peters, G. (2008). Norwegian Consumption, Chinese Pollution: An example of how OECD imports generate CO2 emissions in developing countries. WWF Norway,
- Revesz, R. (1992). Rehabilitating Interstate Competition: Rethinking the Race-to-the-Bottom Rationale for Federal Environmental Regulation. *New York University Law Review* 67(6), 1210-1255. Chicago
- Rezza, A. A. (2015). A meta-analysis of FDI and environmental regulations. *Environment and Development Economics*, 20(02), 185-208.
- Shui, B., & Harriss, R. C. (2006). The role of CO2 embodiment in US–China trade. *Energy Policy*, 34(18), 4063–4068.
- Straumann, R. (2004). Exporting pollution? Calculating the embodied emissions in trade for Norway.
- Taylor, M. S. (2004). Unbundling the pollution haven hypothesis. *Advances in Economic Analysis & Policy*, 3(2).
- Tinbergen, J. (1962). An analysis of world trade flows. *Shaping the world economy*, 1-117.
- Tobey, J. A. (1990). The Effects of Domestic Environmental Policies on Patterns of World Trade: An Empirical Test. *Kyklos*, 43(2), 191–209.
- Van Beers, C., & Van Den Bergh, J. C. (1997). An empirical multi-country analysis of the impact of environmental regulations on foreign trade flows. *Kyklos*, 50(1), 29-46.
- Wagner, G. (2010). Energy content of world trade. *Energy Policy*, 38(12), 7710–7721.
- Weber, C. L., & Matthews, H. S. (2007). Embodied Environmental Emissions in U.S. International Trade, 1997–2004. *Environmental Science & Technology*, 41(14), 4875–4881.

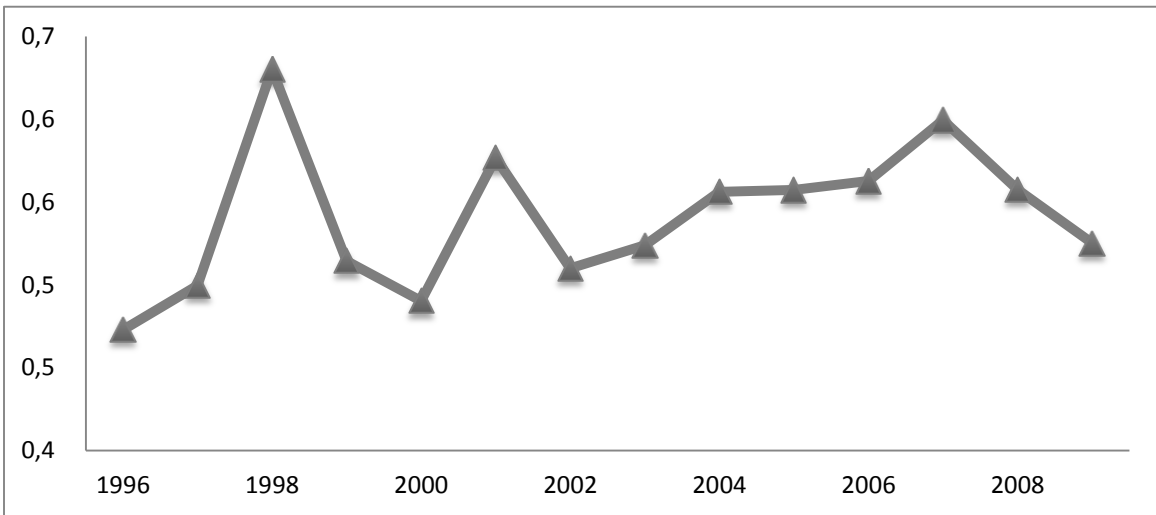


Figure 1. Evolution of China's intensity of carbon embodied in trade and total CTT

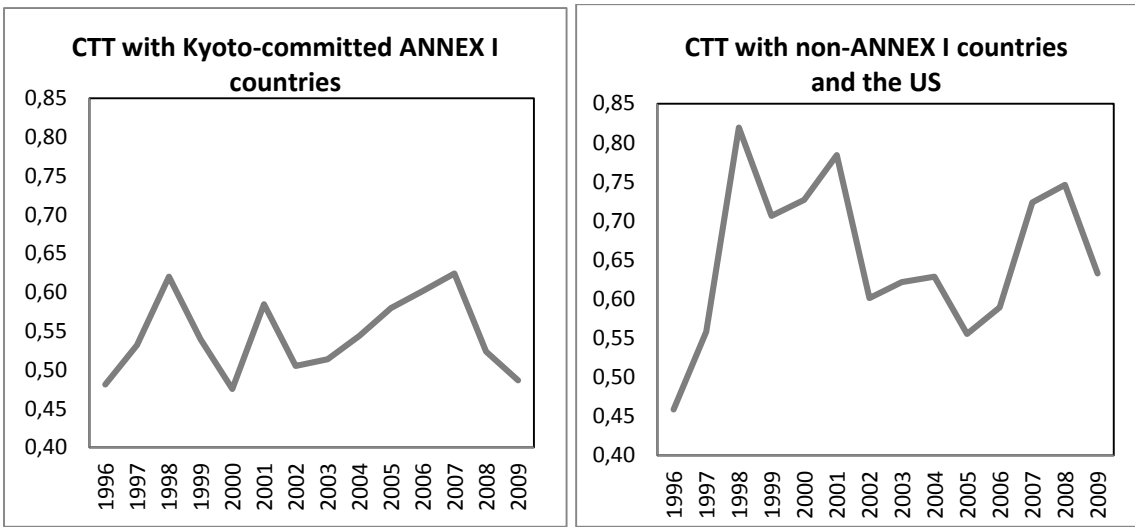


Figure 2. China's intensity of carbon embodied in trade and CTT (by groups of countries)

Table 1 Variables and sources (nb. Observations=770)

<i>Variables</i>	<i>Description</i>	<i>Sources</i>	<i>Mean</i>	<i>Sd.</i>	<i>Min</i>	<i>Max</i>
CTT	Carbon Terms of Trade	Calculated by authors (more details about the calculation is given in Appendix 1)	-0.396	0.598	-2.211	1.848
ΔKL	Capital to labor ratio at 2005 constant prices	Extended Penn World Table 1996-2009*	1.199	1.067	-2.178	4.120
$\Delta FEUL$	Ratio of net fuel exports in the total trade volume	WDI 1996-2009	-0.658	0.893	-3.738	0.312
ΔMIN	Mineral Rent	WDI 1996-2009	-5.238	5.231	-14.787	3.547
ΔSK	Proportion of population over 15 years old with completed primary education with respect to population with less than 4 years of schooling. Data is compiled every five years.	Barro and Lee (2013)	0.834	1.557	-2.794	5.275
$\Delta INNO$	Research and development expenditure (% of GDP)	WDI 1996-2009	1.198	1.081	0.007	5.833
ΔHK	Proportion of population over 15 years old with completed high education with respect to population with less than 4 years of schooling. Data is compiled every five years.	Barro and Lee (2013)	2.163	2.062	-2.334	7.198
ΔREG	General environmental regulation stringency measured by per capita GDP	WDI 1996-2009	1.803	1.37	-1.543	4.181
AnnexI	Annex I countries that ratified the Kyoto Protocol(Time varying, yes=1, no=0)	Appendix 4	0.303	0.460	0	1
Attainment	Kyoto-committed Annex I countries that at least partially attained the carbon reduction target imposed by Kyoto=1, other countries=0, time varying.	Appendix 5	0.144	0.351	0	1
ICCSP1**	Spatial lag of ICC, weighted by simple distance (most populated cities, km)	Calculated by authors	0.019	0.018	0	0.071
ICCSP2**	Spatial lag of ICC, weighted by weighted distance (population-weighted, km)	Calculated by authors				
	CES distances with theta=-1***		0.018	0.018	0	0.062

*: only part of data cover the year from 1996 to 2009, We therefore add the missing ΔKL data to 2009 by employing the method of the Extended Penn World Tables with newer data from PWT 7.1

** i.e., other countries' membership dummies, weighted with distance, all distance measures come from CEPII Database

*** See Clair et al(2004) for detail

Kyoto-committed Annex I Countries: Australia, Austria, Bulgaria, Canada, Croatia, Switzerland, Chile, Czech Republic, Germany, Denmark, Spain, Estonia, Finland, France, United Kingdom, Greece, Hungary, Ireland, Iceland, Italy, Japan, Korea, Mexico, Lithuania, Netherlands, Norway, New Zealand, Poland, Portugal, Russian Federation, Slovakia, Slovenia, Sweden, Turkey, Ukraine.

Annex I country not committed to Kyoto-protocol: United States.

Other Countries: Algeria, Bolivia, Brazil, Ecuador, Egypt, Indonesia, India, Kenya, Israel, Morocco, Malaysia, Pakistan, Peru, Philippines, Paraguay, Thailand, Tunisia, Uruguay, South Africa.

Table 2. Estimation results (country fixed effect and year fixed effect)

	REG only	KP=Kyoto-committed Annex I (<i>annexI</i>)				KP= <i>Attainment</i>			
	FE	FE		FE, IV		FE		FE, IV	
	(1)	(2)	(3)	(2)	(3)	(2)	(3)	(2)	(3)
Δ KL	0.0548 (0.88)	0.0381 (0.62)	0.0406 (0.65)	0.0204 (0.33)	0.0494 (0.80)	0.0549 (0.88)	0.0600 (0.96)	0.0571 (0.74)	0.0662 (1.03)
Δ MIN	-0.00411 (-0.64)	-0.00454 (-0.71)	-0.00448 (-0.70)	-0.00499 (-0.78)	-0.00426 (-0.67)	-0.00421 (-0.65)	-0.00407 (-0.63)	-0.00609 (-0.76)	-0.00466 (-0.70)
Δ FUEL	-0.0999 (-1.23)	-0.0368 (-0.45)	-0.0417 (-0.50)	0.0298 (0.35)	-0.0523 (-0.63)	-0.0865 (-1.05)	-0.0972 (-1.17)	0.168 (1.36)	-0.00716 (-0.08)
Δ SK	-0.121*** (-3.94)	-0.0942*** (-3.04)	-0.0943*** (-3.04)	-0.0658** (-2.04)	-0.0895*** (-2.88)	-0.115*** (-3.69)	-0.115*** (-3.70)	-0.00827 (-0.17)	-0.0728** (-2.09)
Δ HK	0.188*** (3.99)	0.163*** (3.46)	0.161*** (3.40)	0.135*** (2.83)	0.147*** (3.13)	0.178*** (3.70)	0.175*** (3.61)	-0.0130 (-0.16)	0.0949* (1.72)
Δ INNO	0.124*** (2.97)	0.212*** (4.58)	0.209*** (4.47)	0.304*** (5.60)	0.211*** (4.33)	0.137*** (3.14)	0.131*** (2.99)	0.371*** (4.40)	0.219*** (3.98)
Δ REG	0.810*** (4.16)	0.830*** (4.32)	0.796*** (3.83)	0.852*** (4.43)	0.642*** (3.01)	0.771*** (3.90)	0.701*** (3.33)	0.0439 (0.14)	0.339 (1.43)
Δ REG*KP		0.0841*** (4.26)		0.173*** (5.10)		0.0275 (1.04)		0.549*** (3.69)	
Δ REG*KP*FSU			0.120 (1.42)		0.301*** (2.84)		0.107 (1.25)		0.397*** (3.31)
Δ REG*KP*OECD			0.0826*** (4.12)		0.0915*** (3.68)		0.0228 (0.85)		0.226*** (3.08)
Within R2	0.136	0.158	0.159	0.134	0.153	0.138	0.139	-0.343	0.0613
Hausman Test (FE vs. RE)	45.65 (0.009)	53.34 (0.0001)	38.69 (0.0153)	-	-	39.17 (0.0094)	29.01 (0.1447)	-	-
F-Stat	5.48	6.21	5.93	6.10	5.92	5.27	5.07	3.98	5.22
Under-ID test (LM-stat)	-	-	-	241.04 (0.000)	424.076 (0.000)	-	-	34.379 (0.000)	101.475 (0.000)
Over-ID test (Chi2-value)	-	-	-	1.093 (0.296)	0.463 (0.793)	-	-	3.862 (0.0494)	3.168 (0.205)
Weak-ID test (F-stat)	-	-	-	177.043	251.812	-	-	17.502	28.572

t statistics in parentheses, * p<0.1 ** p<0.05 *** p<0.01

55 counties*14 years=770 observations, Environmental regulation proxy: GDPPC

IV: Kyoto policy dummies are instrumented by ICCSP1: the spatial lag of countries' ICC decision with simple distance (from most populated cities, km) and lagged GDP growth rate.

Table 3. Estimation results with decomposed ICEX and ICEM indicators

	ICEX				ICEM			
	AnnexI, FE	AnnexI, FE, IV	Attainment , FE	Attainment, FE, IV	AnnexI, FE	AnnexI, FE, IV	Attainment , FE	Attainment , FE, IV
Δ KL	0.0101 (0.39)	0.0218 (0.84)	0.0204 (0.78)	0.0284 (1.01)	-0.0306 (-0.52)	-0.0276 (-0.48)	-0.0397 (-0.68)	-0.0378 (-0.65)
Δ MIN	0.00306 (1.15)	0.00335 (1.26)	0.00336 (1.24)	0.00314 (1.08)	0.00754 (1.25)	0.00761 (1.29)	0.00743 (1.23)	0.00780 (1.30)
Δ FUEL	0.0365 (1.06)	0.0157 (0.45)	-0.00278 (-0.08)	0.0406 (1.00)	0.0782 (1.01)	0.0680 (0.88)	0.0944 (1.22)	0.0477 (0.57)
Δ SK	0.00648 (0.50)	0.00731 (0.56)	-0.00831 (-0.64)	0.0166 (1.09)	0.101*** (3.45)	0.0968*** (3.33)	0.107*** (3.68)	0.0894*** (2.85)
Δ HK	-0.00619 (-0.31)	-0.0163 (-0.82)	0.00790 (0.39)	-0.0419* (-1.74)	-0.167*** (-3.76)	-0.164*** (-3.71)	-0.167*** (-3.70)	-0.137*** (-2.76)
Δ INNO	-0.0184 (-0.94)	-0.0292 (-1.41)	-0.0669*** (-3.64)	-0.0203 (-0.84)	-0.227*** (-5.17)	-0.240*** (-5.26)	-0.198*** (-4.85)	-0.239*** (-4.83)
Δ REG	-0.207** (-2.39)	-0.372*** (-4.12)	-0.235*** (-2.66)	-0.508*** (-4.90)	-1.003*** (-5.14)	-1.013*** (-5.07)	-0.936*** (-4.78)	-0.847*** (-3.97)
Δ REG* KP *FSU	0.238*** (6.79)	0.415*** (9.26)	0.222*** (6.19)	0.462*** (8.79)	0.118 (1.49)	0.114 (1.15)	0.115 (1.45)	0.0645 (0.60)
Δ REG* KP* OECD	0.0410*** (4.91)	0.0373*** (3.54)	-0.0104 (-0.92)	0.104*** (3.25)	-0.0417** (-2.21)	-0.0542** (-2.32)	-0.0332 (-1.32)	-0.121* (-1.84)
Within R2	0.214	0.184	0.1876	0.033	0.152	0.151	0.148	0.133
Hausman Test (FE vs. RE)	35.73 (0.0324)		42.8 (0.000)		22.70 (0.4186)		49.44 (0.0007)	
F-Stat	8.57	9.41	7.27	7.93	5.63	5.61	5.47	5.41
Under-ID test (LM-stat)		424.076 (0.000)		101.475 (0.000)		424.076 (0.000)		101.475 (0.000)
Over-ID test (Chi2-value)		4.525 (0.104)		3.848 (0.146)		1.990 (0.370)		3.861 (0.145)
Weak-ID test (F-stat)		251.815		28.572		251.815		28.572

t statistics in parentheses, * p<0.1 ** p<0.05 *** p<0.01

55 counties*14 years=770 observations, Environmental regulation proxy: GDPPC

IV: Kyoto policy dummies are instrumented by ICCSP1: the spatial lag of countries' ICC decision with simple distance (from most populated cities, km) and lagged GDP growth rate.

Table 4. Verification of carbon leakage via other environmental regulation measurements (CTT)

Description of regulatory variable	Exp. sign	Reg	Reg *AnnexI	Reg	Reg*AnnexI *FSU	Reg *AnnexI *OECD	Reg	Reg *Attainment	Reg	Reg *Attainment *FSU	Reg *Attainment *OECD
CO2 emission	-	-0.798***	-0.0596***	-0.902***	-0.0836***	-0.0183	-0.710***	-0.0982***	-0.964***	-0.0740***	0.0000695
CO2 emission intensity	-	-1.000***	-0.155***	-0.990***	-0.209	-0.0719**	-0.391	-0.539***	-0.901***	-0.228	-0.0872
Energy Intensity	-	-0.270***	-0.140***	-0.303***	-0.107	-0.0903**	-0.162	-0.308*	-0.323***	-0.112	-0.0616
Standardized Energy use per GDP	-	-0.137***	-0.188***	-0.141***	-0.542	-0.140***	0.00536	-0.890***	-0.0680	-0.823	-0.490**
Energy Consumption Intensity(1)	-	-0.303***	-0.175***	-0.339***	-0.215	-0.0823**	-0.177*	-0.608***	-0.338***	-0.239	-0.111
Energy Consumption Intensity(2)	-	-0.684***	-0.306***	-0.702***	-0.0333	-0.216**	-0.540***	-0.700**	-0.721***	-0.134	-0.149
Standardized reduction in CO ₂ Emissions	+	-0.0179	0.128***	-0.00853	0.141**	0.0738***	-0.00281	0.157***	0.000324	0.126**	0.111**
Percent reduction in CO ₂ emission adjusted for changes in GDP	+	-0.0113	0.137***	0.00000491	0.147***	0.0712***	0.00122	0.174***	0.00764	0.136***	0.0975**
Annual change in Energy Intensity	+	0.0337	-0.00266	0.0259	0.0436	-0.00361	0.0286	0.0135	0.0392*	0.0275	-0.0873
Ranked Energy Efficiency	+	0.243***	0.115**	0.275***	-0.0744	0.0776**	0.193*	0.232*	0.318***	-0.0622	0.0156
Narrow Index	+	0.0916***	-0.105***	0.0703***	0.0164	-0.0821***	0.0874***	-0.121**	0.0683***	0.0286	-0.119**
ENVPOL	+	-0.0570	0.0946	-0.0490	-0.000622	0.0907*	-0.0343	0.0422	-0.0445	-0.0230	0.0948
Standardized Treaties	+	-0.0919	0.128***	-0.0839	0.0452	0.0644*	-0.0935	0.209**	-0.0696	0.0398	0.00369
Standardized ISO 14000	+	0.127***	0.114	0.118***	-0.245*	0.163	0.130***	0.165	0.111***	-0.257*	0.520*
Standardized Environmental NGO	+	0.140	0.138***	0.0623	0.198***	0.0698***	0.0323	0.265***	0.111	0.180***	0.0642
Patent	+	-0.0479	0.0455	-0.0289	-0.131**	0.0163	-0.0531*	0.0810*	-0.0314	-0.129**	0.0311
INGO	+	0.401*	0.0752***	0.488**	0.0920***	0.0324**	-0.0210	0.173***	0.614***	0.0733**	0.0150
Stringency of environmental regulation	+	0.180	-0.0785	0.155	0.796**	-0.0567	0.177	-0.0770	0.161	0.797**	-0.137
Enforcement of environmental regulation	+	-0.0859	0.974**	-0.164	2.266***	0.707*	-0.0575	1.513**	-0.152	2.252***	1.568**
Domestic effort for CO2 reduction	-	-0.109	-0.131**	-0.108	-2.505***	-0.0439	0.0537	-0.582*	-0.0645	-2.493***	-0.137
Domestic effort for SO2 reduction	-	0.0951**	-0.0611	0.0971**	-0.807***	-0.0305	0.0881**	-0.0796	0.0914**	-0.797***	-0.0774
Production-based proxy for the level of environmental stringency	+	1.314***	0.505***	1.358***	-2.109***	0.675***	1.394***	1.437**	1.527***	-2.338***	2.567***
Environmental Performance Index (EPI)	+	-0.182	0.160	-0.234	0.0232	0.191	-0.112	-0.284	-0.293	0.0509	0.495
ER Index	+	0.815***	0.230***	0.909***	0.257*	0.0894*	0.257	0.837***	0.967***	0.198	0.0480
ER Index (2)	+	0.102	0.213***	0.126	0.393***	0.111***	-0.0279	0.625***	0.157	0.358***	0.104

Bold numbers are coefficients with expected signs. * is used to present the statistical significance of the estimated coefficients, * p<0.1 ** p <0.05 *** p<0.01

55 counties*14 years=770 observations, Environmental regulation proxy: GDPPC

IV: Kyoto policy dummies are instrumented by ICCSP1: the spatial lag of countries' ICC decision with simple distance (from most populated cities, km) and lagged GDP growth rate.

Table 5. Robustness check 1: instrumentation strategies (CCT)

Instrumentation strategies used for Kyoto-related policy variables	Reg	Reg *AnnexI	Reg	Reg*AnnexI *FSU	Reg *AnnexI *OECD	Reg	Reg *Attainment	Reg	Reg* Attainment *FSU	Reg* Attainment *OECD
spatial lag of ICC decision with weighted distance (pop-wt, km)	0.693 (3.58)***	0.161 (4.86)***	0.543 (4.42)***	0.248 (2.28)**	0.091 (3.73)***	-0.083 (0.28)	0.519 (3.85)***	0.230 (0.99)	0.338 (2.77)***	0.226 (3.18)***
F-Stat	5.15		4.70		3.38		4.14			
R2	0.112		0.128		-0.339		0.036			
Under-ID test (LM-stat)	242.861		422.472		38.878		103.266			
Over-ID test (Sargan, Chi2-value)	0.923		0.817		0.359		0.239			
Weak-ID test (F-stat)	179.213		253.533		19.930		29.206			
the spatial lag of countries' ICC decision with simple distance, LIM1	0.692 (3.58)***	0.158 (4.75)***	0.555 (2.64)***	0.228 (2.04)**	0.088 (3.59)***	-0.153 (0.52)	0.577 (4.09)***	0.244 (1.05)	0.321 (2.57)**	0.223 (3.11)***
F-Stat	5.10		4.62		3.25		4.10			
R2	0.114		0.129		-0.454		0.038			
Under-ID test (LM-stat)	239.780		405.71		39.514		102.838			
Over-ID test (Sargan, Chi2-value)	0.936		0.849		0.749		0.285			
Weak-ID test (F-stat)	175.773		229.928		10.108		29.064			
lagged growth rate of population	0.686 (3.30)***	0.144 (0.80)	0.600 (1.84)*	0.134 (0.35)	0.066 (1.39)	0.316 (0.71)	0.225 (0.77)	0.367 (0.85)	0.225 (0.51)	0.142 (1.35)
F-Stat	4.12		4.05		3.78		3.86			
R2	0.1202		0.131		0.041		0.087			
Under-ID test (LM-stat)	8.164		31.946		5.849		22.616			
Over-ID test (Sargan, Chi2-value)	-		-		-		-			
Weak-ID test (F-stat)	8.014		16.209		5.772		11.318			
Wooldridge two-step procedure (%)	0.686 (3.30)***	0.144 (0.80)	0.611 (2.78)***	0.160 (1.12)	0.092 (4.02)***	0.399 (1.14)	0.164 (0.77)	0.321 (1.32)	0.268 (1.69)*	0.162 (2.20)**
F-Stat	4.12		4.68		3.94		3.98			
R2	0.120		0.132		0.079		0.077			
Under-ID test (LM-stat)	8.164		253.07		10.572		91.314			
Under-ID test (LM-stat)	-		-		-		-			
Weak-ID test (F-stat)	8.014		190.95		10.414		50.797			
Wooldridge two-step procedure (Prob>50% =1, other =0)	0.832 (4.39)***	0.091 (1.86)*	1.072 (4.76)***	-0.130 (1.02)	0.126 (2.95)***	0.248 (0.45)	0.403 (1.11)	0.731 (2.62)***	0.011 (0.06)	0.142 (1.82)*
F-Stat	5.51		5.47		4.11		4.98			
R2	0.158		0.141		-0.111		0.11			
Under-ID test (LM-stat)	114.03		155.543		4.806		82.3621			
Under-ID test (LM-stat)	-		-		-		-			
Weak-ID test (F-stat)	131.682		96.335		4.696		45.110			

Table 6. Robustness check 1: instrumentation strategies (ICEX)

Instrumentation strategies used for Kyoto-related policy variables	Reg	Reg *Annex I	Reg	Reg*AnnexI *FSU	Reg *AnnexI *OECD	Reg	Reg *Attainment	Reg	Reg* Attainment *FSU	Reg* Attainment *OECD
spatial lag of ICC decision with weighted distance (pop-wt, km)	-0.099 (1.21)	0.071 (5.09)***	-0.400 (4.50)***	0.415 (8.95)***	0.039 (3.74)***	-0.417 (3.25)***	0.211 (3.65)***	-0.544 (5.32)***	0.459 (8.54)***	0.105 (3.37)***
Within R2		0.179		0.184		-0.269			0.033	
F-Stat		7.29		9.68		4.56			8.14	
Under-ID test (LM-stat)		242.961		422.472		38.878			103.266	
Over-ID test (Chi2-value)		0.04		0.09		0.01			0.10	
Weak-ID test (F-stat)		179.213		253.533		19.93			29.206	
the spatial lag of countries' ICC decision with simple distance, LIMI	-0.102 (1.25)	0.066 (4.67)***	-0.398 (4.46)***	0.405 (8.53)***	0.035 (3.32)***	-0.454 (3.20)***	0.238 (3.43)***	-0.534 (5.22)***	0.450 (8.18)***	0.101 (3.19)***
Within R2		0.183		0.187		-0.387			0.045	
F-Stat		7.13		9.28		4.15			7.93	
Under-ID test (LM-stat)		239.78		405.710		34.958			102.838	
Over-ID test (Chi2-value)		0.047		0.091		0.017			0.142	
Weak-ID test (F-stat)		175.773		229.928		17.816			29.064	
lagged growth rate of population	-0.167 (1.64)	-0.083 (0.94)	-0.164 (1.18)	0.064 (0.39)	0.013 (0.66)	0.045 (0.22)	-0.139 (0.97)	-0.211 (1.16)	0.083 (0.44)	0.029 (0.65)
Within R2		-0.096		0.187		-0.020			0.162	
F-Stat		4.60		5.88		4.95			5.71	
Under-ID test (LM-stat)		8.164		31.946		5.849			22.616	
Over-ID test (Chi2-value)		-		-		-			-	
Weak-ID test (F-stat)		8.014		16.209		5.722			11.318	
Wooldridge two-step procedure (%)	-0.116 (1.42)	0.034 (1.73)*	-0.172 (1.92)*	0.111 (2.12)**	0.036 (3.79)***	-0.372 (2.45)**	0.177 (2.05)**	-0.382 (3.69)***	0.255 (3.98)***	0.095 (3.02)***
Within R2		0.187		0.207		-0.144			0.091	
F-Stat		6.29		6.77		4.56			6.08	
Under-ID test (LM-stat)		121.792		333.717		15.567			95.431	
Over-ID test (Chi2-value)		-		-		-			-	
Weak-ID test (F-stat)		142.768		306.198		15.445			53.444	
Wooldridge two-step procedure (Prob>50% =1, other =0)	-0.029 (0.35)	0.038 (1.91)*	-0.040 (0.39)	0.048 (0.68)	0.036 (3.64)***	-0.328 (1.75)*	0.208 (1.83)*	-0.240 (2.09)**	0.172 (2.21)**	0.093 (2.88)***
Within R2		0.177		0.181		0.261			0.080	
F-Stat		5.75		5.93		3.80			5.22	
Under-ID test (LM-stat)		120.949		180.409		10.303			95.953	
Over-ID test (Chi2-value)		-		-		-			-	
Weak-ID test (F-stat)		141.299		116.934		10.147			52.419	

Table 7. Robustness check 1: instrumentation strategies (ICEM)

Instrumentation strategies used for Kyoto-related policy variables	Reg	Reg *Annex I	Reg	Reg*AnnexI *FSU	Reg *AnnexI *OECD	Reg	Reg *Attainment	Reg	Reg* Attainment *FSU	Reg* Attainment *OECD
spatial lag of ICC decision with weighted distance (pop-wt, km)	-0.793 (4.34)***	-0.090 (2.87)***	-0.943 (4.77)***	0.166 (1.62)	-0.052 (2.27)**	-0.297 (5.05)***	-0.335 (3.09)***	-0.773 (3.68)***	0.120 (1.09)	-0.120 (1.87)*
Within R2		0.112		0.128		-0.082			0.110	
F-Stat		4.71		4.59		4.00			4.43	
Under-ID test (LM-stat)		242.861		422.472		43.101			103.266	
Over-ID test (Chi2-value)		0.414		0.637		0.837			0.296	
Weak-ID test (F-stat)		179.213		253.533		11.085			29.206	
the spatial lag of countries' ICC decision with simple distance, LIMI	-0.794 (5.39)***	-0.092 (2.9)***	-0.921 (4.80)***	0.175 (1.66)*	-0.053 (2.30)**	-0.302 (1.17)	-0.332 (2.76)***	-0.776 (3.66)***	0.126 (1.11)	-0.124 (1.90)*
Within R2		0.111		0.128		-0.077			0.109	
F-Stat		4.72		4.61		3.92			4.44	
Under-ID test (LM-stat)		239.78		405.71		34.958			102.838	
Over-ID test (Chi2-value)		0.423		0.595		0.933			0.266	
Weak-ID test (F-stat)		175.773		229.928		17.816			29.064	
lagged growth rate of population	-0.853 (4.05)***	-0.226 (1.24)	-0.764 (2.46)**	-0.070 (0.19)	-0.053 (1.16)	-0.271 (0.60)	-0.355 (1.19)	-0.578 (1.43)	-0.142 (0.34)	-0.113 (1.15)
Within R2		-0.013		0.120		-0.108			0.102	
F-Stat		3.87		4.25		3.54			4.16	
Under-ID test (LM-stat)		8.164		31.946		5.849			22.66	
Over-ID test (Chi2-value)		-		-		-			-	
Weak-ID test (F-stat)		8.014		16.209		5.722			11.318	
Wooldridge two-step procedure (%)	-0.763 (4.19)	-0.022 (0.50)	-0.840 (5.40)***	0.021 (0.18)	-0.059 (2.74)***	-0.592 (2.05)**	-0.119 (0.72)	-0.766 (3.51)***	0.068 (0.51)	-0.066 (0.99)
Within R2		0.122		0.125		0.102			0.123	
F-Stat		4.39		4.53		4.31			4.25	
Under-ID test (LM-stat)		121.782		333.717		15.567			95.431	
Over-ID test (Chi2-value)		-		-		-			-	
Weak-ID test (F-stat)		142.768		306.198		15.445			53.444	
Wooldridge two-step procedure (Prob>50% =1, other =0)	-0.854 (3.44)***	-0.028 (0.63)	-1.010 (4.47)***	0.109 (0.70)	-0.055 (2.52)**	-0.816 (2.43)***	-0.023 (0.11)	-1.021 (4.25)***	0.216 (1.33)	-0.149 (0.72)
Within R2		0.147		0.1511		0.144			0.145	
F-Stat		5.53		5.62		5.50			5.38	
Under-ID test (LM-stat)		120.949		180.409		10.303			93.953	
Over-ID test (Chi2-value)		-		-		-			-	
Weak-ID test (F-stat)		141.299		116.934		10.147			52.419	

Appendix 1. The calculation of sector-level carbon emission intensity

This part discusses the methods for calculation of indirect carbon dioxide emission intensity. Firstly, we follow IPCC's < **Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories**> to estimate carbon dioxide emission volume of 28 industries from energy data of China. The estimation process can be divided into six steps that lead to figures for CO2 emissions from fuel combustion.

1. Estimate consumption of fuels by fuel/product type.
2. Convert the fuel data to a common energy unit (TJ)
3. Because carbon and energy content by weight differ markedly between fuels, we have to select carbon emission factors for each fuel/product type and estimate the total carbon content of the fuels.
4. Estimate the amount of carbon stored in products for long periods of time.
5. Account for carbon not oxidised during combustion.
6. Convert emissions of carbon to the full molecular weight of CO2 .

Taken together, we use the equation to estimate emission volume of CO2 of each manufacturing industry:

$$CE_{lt} = \sum_j CE_{ljt} = \sum_j E_{ljt} EF_j (1 - CS_{jt}) O_j M \quad (1)$$

where CE_{lt} refers to the total emission of CO2 of the lth industry in period t, CE_{ljt} is total emission of CO2 of the lth industry in period t from the jth fuel, E_{ljt} is the total amount of the jth fuel consumed by the lth industry in period t, EF_j is the emission factor of the lth industry, CS_j is the coefficient of carbon stored in products from the jth fuel, O_j is the ratio of the jth fuel that oxidised during combustion, and M is the ratio of molecular weight of CO2 and C.

The direct emission intensity of the lth industry can be given as $\delta_{lt} = CE_{lt}/Y_{lt}$, Y_{lt} is the gross output of the lth industry. Because direct emission intensity cannot fully reflect the responsibility of industry for carbon emission, it will lead to a biased estimation of the carbon effluent embodied in trade. We therefore use an IO model to get the total emission intensity of the lth industry. Following the previous literature, the total output of industry satisfies equation: $x = Ax + y$, where x refers to total output vector, y is the total consumption vector, and A is a direct consumption matrix. We can rephrase the equation as $x = (I - A)^{-1}y$. $(I - A)^{-1}$ is the so-called Leontief inverse matrix. Taking α_{jl} as the lth column and jth row element of the Leontief inverse matrix, the total emission intensity can be written as: $\epsilon_{lt} = \sum_j \delta_{lt} \alpha_{jl}$.

Appendix 2. Variables description and Data source

Variable	Description	Source
E	gross volume of the 16 kinds of fuel usage of 28 manufacturing industries	CHINA ENERGY STATISTICAL YEARBOOK 1997-2010
S	ratio of the amount of a fuel which is used as an industrial raw material with respect to the amount that is used in providing energy,	CHINA ENERGY STATISTICAL YEARBOOK 1997-2010
F	carbon dioxide emission coefficient per unit for the 16 kinds of fuel	IPCC 1996
O	degree of oxidation of fuel in combustion	IPCC 1996
Y	gross output value of manufacturing industries	CHINA STATISTICAL YEARBOOK 1997-2010

Appendix 3. Sectors list

1. Food processing,
 2. Food Manufacturing,
 3. Beverage Manufacturing,
 4. Tobacco Processing,
 5. Textiles, Garments and Other Fiber products,
 6. Leather, Furs, Down and Related Products,
 7. Timber Processing, Bamboo, Cane, Palm Fiber and Straw Products
 8. Furniture Manufacture,
 9. Paper-Making and Paper Products,
 10. Printing and Record processing
 11. Cultural, Educational and Sports Articles,
 12. Petroleum Processing and Coking Products,
 13. Chemicals and Allied Products,
 14. Chemical and Pharmaceutical Products,
 15. Chemical Fibers,
 16. Rubber Products,
 17. Plastics Products,
 18. Building Materials and Other Non-Metal Mineral Products,
 19. Smelting and Pressing of Ferrous Metals,
 20. Smelting and Pressing of non-Ferrous Metals,
 21. Metal Products,
 22. Ordinary Machine Manufacturing,
 23. Special Purpose Equipment Manufacturing,
 24. Transportation Equipment Manufacturing,
 25. Electric Equipment and Machinery,
 26. Electric and Telecommunications Instruments,
 27. Cultural and Official Machinery,
 28. Other Manufacturing
-

Appendix 4. Lists of countries used in our paper and their group

Kyoto-committed annex1 Countries (31)	Australia, Austria, Bulgaria, Canada, Croatia, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Japan, Lithuania, Netherlands, New Zealand, Norway, Poland, Portugal, Russian Federation, Slovak Republic, Slovenia, Spain, Sweden, Switzerland, Ukraine, United Kingdom
Non-Annex I Countries and the US (24)	Algeria, Bolivia, Brazil, Chile, Ecuador, Egypt, Indonesia, India, Israel, Kenya, South Korea, Malaysia, Mexico, Morocco, Pakistan, Peru, Philippines, Paraguay, South Africa, Thailand, Tunisia, Turkey, Uruguay, United States (Annex I country that did not ratify the Kyoto Protocol)

Appendix 5. The Kyoto carbon control attainment details

(Table adapted from the Table 1. World CO₂ emission from fuel combustion and Kyoto Protocol Targets, CO₂ emission from fuel combustion: Highlights, IEA statistics, 2011 Ed. P13, <http://www.iea.org/media/statistics/co2highlights.pdf>)

Annex I countries committed to carbon control targets (35 in total)	Carbon control target to be achieved by 2012 with respect to 1990 (%)	Change in carbon emissions in 2009 compared to those in 1990 (%)	Attainment (attained fully or partially the carbon control target)	Former Soviet Union (FSU) countries
Australia	8	51.8	0	0
Austria	-13	12.2	0	0
Belgium*	-7.5	-6.7	n.i	n.i
Bulgaria	-8	-43.7	1	1
Canada	-6	20.4	0	0
Croatia	-5	-8.4	1	1
Czech Republic	-8	-29.2	1	1
Denmark	-21	-7.2	0	0
Estonia	-8	-59.4	1	1
Finland	0	1.1	0	0
France	0	0.6	0	0
Germany	-21	-21.1	1	0
Greece	25	28.6	0	0
Hungary	-6	-27.8	1	1
Iceland	10	6.2	1	0
Ireland	13	32.4	0	0
Italy	-6.5	-2	1	0
Japan	-6	2.7	0	0
Latvia*	-8	-63.8	n.i	n.i
Lithuania	-8	-62.6	1	1
Luxembourg*	-28	-4.4	n.i	n.i
Netherlands	-6	13	0	0
New Zealand	0	34.3	0	0
Norway	1	31.9	0	0
Poland	-6	-16.2	1	1
Portugal	27	35.3	0	0
Romania*	-8	-53.1	n.i	n.i
Russian Federation	0	-29.7	1	1
Slovak Republic	-8	-41.5	1	1
Slovenia	-8	21.2	0	1
Spain	15	37.7	0	0
Sweden	4	-20.9	1	0
Switzerland	-8	2.5	0	0
Ukraine	0	-62.7	1	1
United Kingdom	-12.5	-15.2	1	0

1. The US is an Annex I country under the UNFCCC but it did not ratify the Kyoto Protocol.

2. On December 15, 2011, the Depositary received written notification of Canada's withdrawal from the Kyoto Protocol. This action became effective for Canada on December 15, 2012, which does not affect the status of Canada during the period of our study

3. The targets for the first commitment period of the Kyoto Protocol cover emissions of the six main greenhouse gases, namely: Carbon dioxide (CO₂); Methane (CH₄); Nitrous oxide (N₂O); Hydrofluorocarbons (HFCs); Perfluorocarbons (PFCs); and Sulfur hexafluoride (SF₆)

4. The maximum amount of emissions (measured as the equivalent in carbon dioxide) that a Party may emit over a commitment period in order to comply with its emissions target is known as a Party's **assigned amount**. The individual targets for Annex I Parties are listed in the Kyoto Protocol's Annex B.

5. * means the country is not in our database; there are in total 4 countries not in our database.

Appendix 6. Regulation proxies used in robustness check and its expected sign of coefficient

1. Emissions and energy use				
Measure	Data source ¹	Studies	Notes	Exp. sign
CO2 emission	WDI	Costantini and Crespi (2008)	Economy-wide emissions of carbon dioxide.	-
CO2 emission intensity	WDI	Cagatay and Mihci (2003, 2006)	Economy-wide emissions of carbon dioxide divided by GDP** measured in constant 2005 US dollars (official exchange rate).	-
Energy use per GDP	WDI	Van Beers and Van Den Bergh (1997)	Megatons oil equivalent per 1000 unit of current GNP**	-
Standardized Energy use per GDP*	WDI	Cole and Elliott (2003)	Kilograms of oil equivalent of energy per unit of constant GDP** in purchasing-power parities (PPP). Then the values of different countries are standardized to a distribution of zero mean and unity standard deviation.	-
Energy Consumption Intensity_1	WDI	Harris et al. (2002)	Total final consumption of energy (Mtoe) divided by GDP** in purchasing-power parities (PPP)	-
Energy Consumption Intensity_2	WDI	Harris et al. (2002)	Total final consumption of energy (Mtoe), divided by GDP** at the official exchange rate	-
2. pollution abatement and environmental protection				
Standardized reduction in CO2 Emissions*	WDI	Smarzynska and Wei (2004)	Standardized % reduction in CO ₂ emission = $(CO_{2,t-1} - CO_{2,t}) / CO_{2,t-1} \times 100\%$	+
Percent reduction in CO2 emission adjusted for changes in GDP*	WDI	Smarzynska and Wei (2004)	Sum of Standardized % reduction in CO ₂ emission and GDP** growth rate.	+
Standardized annual change in	WDI	Cole (2003)	Energy intensity _{t-1} - Energy Intensity _t	+
Standardized Energy Efficiency*	WDI	Ben Kheder and Zugravu (2012)	Energy used per unit of GDP** adjusted by the latitude of the country with the aim of including the differences in climate/weather in the countries under consideration.	+
Narrow Index	WDI	Van Beers and Van Den Bergh (1997)	Van Beers and Van Den Bergh (1997) constructed this index of change of energy intensity and level of energy intensity during the period 1980-1991. Level of energy intensity in 1980 is measured in megatons oil equivalent per 1000 units of current GNP** included. We extend this index to the period 1996 to 2009 by using more recent data from WDI.	+
ENVPOL	WDI	Cole and Elliott (2003)	ENVPOL is calculated based on changes in energy intensity and level of energy intensity, where level of energy intensity refers to Energy Use/GDP**. Then we apply the standard normal percentile technique, which gives the value "0" to the lowest average Z-score and "100" to the highest.	+
3. Institutional Indexes				

Standardized Treaties*	WDI	Ben Kheder and Zugravu (2012)	Number of International Treaties Ratified. We followed Ben Kheder and Zugravu (2012) and applied the standard normal percentile technique to the index, which gives the value “0” to the lowest average Z-score and “100” to the highest.	+
Standardized ISO 14000*	ISO	Ben Kheder and Zugravu (2012)	ISO 14001 certifications per million US dollars GDP. We followed Ben Kheder and Zugravu (2012) and applied the standard normal percentile technique to the index, which gives the value “0” to the lowest average Z-score and “100” to the highest.	+
Standardized Environmental NGP*	Union of International Associations	Ben Kheder and Zugravu (2012)	Number of environmental NGOs per million people. We followed Ben Kheder and Zugravu (2012) and applied the standard normal percentile technique to the index, which gives the value “0” to the lowest average Z-score and “100” to the highest.	+
<i>Patent</i>	OECD Statistics	Johnstone et al.(2010)	Count of number of renewable energy patents	+
<i>Ingo</i>	Union of International Associations	Ben Kheder and Zugravu (2012)	Number of environmental NGOs per million people,	+
4. Composite indexes				
Stringency of environmental regulation	World Executive Opinion Survey , World Economic Forum	Kellenberg (2009); Johnstone and Kalamova (2010)	Based on question “ how would you assess the stringency of your country’s environmental regulations? ”[1 = very lax; 7 = among world’s most stringent]	+
Enforcement of environmental regulation	World Executive Opinion Survey , World Economic Forum	Kellenberg (2009); Johnstone and Kalamova (2010)	Based on question “ how would you assess the enforcement of environmental regulations in your country? ”[1 = very lax; 7 = among world’s most stringent]	+
Domestic effort for CO2 reduction*	Combes et al. (2014)	Original data comes from several database, such as WDI, University of Texas Inequality Project Database, International Financial Statistics, EUROSTAT.	The panel database of 128 countries over 1980-2010 is used to firstly regress a CO ₂ emission determination function. Factors like income per capita, population growth, economic growth and lagged level of emissions, and environmental degradation are included in the analytical framework. The residual of this function is used as a measurement of domestic effort for environmental protection. A negative sign of the residues signifies successful environmental policies.	-
Domestic effort for SO2 reduction*	Combes et al. (2014)	Original data comes from several database, such as WDI, University of Texas Inequality Project database, International Financial Statistics, EUROSTAT.	The panel database of 128 countries over 1980-2010 is used to firstly regress a SO ₂ emission determination function. Factors like income per capita, population growth, economic growth and lagged level of emissions, and environmental degradation are included in the analytical framework. The residual of this function is used as a measurement of domestic effort for environmental protection. A negative sign of the residues signifies successful environmental policies.	-
Production-based proxy for the level	Eliste and Fredriksson (2002), WDI	Damania et al. (2003)	Eliste and Fredriksson (2002) extend the initial index proposed in Dasgupta et al. (1995). We followed the forecasting techniques of Damania et al. (2003) to construct a panel data set for 55 of our countries.	+

of environmental stringency			To proceed, we model the environmental index accordingly: $DAS_i = \beta Z + \omega_i$, where DAS refers to Eliste and Fredriksson (2002)'s index, Z includes variables that influence a country's environmental regulatory stringency: real GDP**, real GDP** squared, percent of population living in urban areas, percent of labor force in industry, and overall population. We then used the estimated β in the above equation and variables to construct forecasting values of environmental stringency in 1996–2010 for the 55 countries of interest.	
Environmental Performance Index (EPI)	Yale University	Damania et al. (2003)	The Environmental Performance Index (EPI) is constructed through the calculation and aggregation of 20 indicators reflecting national-level environmental data. These indicators are combined into nine issue categories, each of which fits under one of two overarching objectives: Environmental Health and Ecosystem Vitality. Environmental Health measures the protection of human health from environmental harm. Ecosystem Vitality measures ecosystem protection and resource management. These two objectives are further divided into nine issue categories that span high-priority environmental policy issues, including air quality, forests, fisheries, and climate and energy, among others.	+
<i>ER Index</i>	WDI, ISO, Union of International Associations	Ben Kheder and Zugravu (2010)	Ben Kheder and Zugravu (2010)'s ER index integrates four variables, which have the advantage of permitting cross-national comparisons in a systematic and quantitative fashion. The four variables used in the calculation of composite indicators are Multilateral Environmental Agreements (MEAs ratified), International NGOs (INGOs' members/millions of population), ISO 14001 (ISO 14001 certifications/billion GDP**) and energy efficiency (GDP**/unit of energy used). The authors calculate the unweighted average of all variables' Z-scores. Then, they apply the standard normal percentile technique, which gives the value "0" to the least average Z-score and "100" to the highest and sum them together.	+
<i>ER Index2</i>	WDI, ISO, Union of International Associations	Ben Kheder and Zugravu (2012)	Ben Kheder and Zugravu (2012)'s ER index2 integrates only 3 variables, which are Multilateral Environmental Agreements (MEAs ratified), International NGOs (INGOs' members/millions of population) and energy efficiency (GDP**/unit of energy used). The authors calculate the unweighted average of all variables' Z-scores. Then, they apply the standard normal percentile technique, which gives the value "0" to the least average Z-score and "100" to the highest and sum them together.	+

*: Since there may be negative values, which makes it impossible to generate a comparable ratio between countries, we calculated the unweighted average of all variables' Z-scores, and applied the standard normal percentile technique to the index, which gives the value "0" to the least average Z-score and "100" to the highest.

** : In US Dollars

+: Data source that we used to compile the related regulation stringency measurement. The construction of various measurements follows the initial method proposed in above-mentioned articles. If possible, the same data sources as used in original paper are prioritized. However, facing the unavailability of the original data source for some measurements for the periods and countries in which we are interested, we used different data sources.