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Is « Pollution Haven » Hypothesis valid for China's manufacture sectors? An empirical analysis based on carbon embodied in trade

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Abstract

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Keyword: Single-country linked Input-Output model, Pollution Haven Hypothesis, Carbon leakage, Comparative advantage, BEET, Pollution terms of trade, China

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Abstract

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1. Introduction

Kyoto Protocol is for the moment the most widely accepted international treaty which aims at reducing the global greenhouse gas (GHG) emission of the signatory nations. This protocol is based on the principle named "common but differentiated responsibility", which separates the governments into Annex I and Non-Annex I countries. It requires the Annex I countries to reduce their GHG emissions by an average of 5.2% below their 1990 levels during 2008-2012 while the Non-Annex I economics have no GHG emission reduction objective.

Some authors think this "common but differentiated responsibility" between Annex I and non-Annex I countries may create the incentive for the Annex I countries to dislocate the carbon intensive industries toward their non-Annex I trade partners and subsequently import the final product for domestic consumption and therefore creates the "carbon leakage". (Oliveira-Martins et al, 1992; Perroni and Runtherford, 1993) If the currently observed downward bending tendency of GHG emission in the Annex I country is simply "compensated" by the increase trend in some non-Annex I countries, the global carbon stabilisation/reduction objectives will not be achieved. Even worse, as the carbon intensity in non-Annex countries is generally higher, the carbon leakage procedure can even push up total GHG emission and accelerate global warming process.

The "carbon leakage" phenomenon has been largely studied since 1990s by authors using environmental Input-Output models. The principal idea of these studies is to use input-output analysis to capture both *direct* emission related to production of traded manufacturing goods and all *indirect* pollution emitted by the upstream sectors which provide intermediary inputs for production of the goods. Most of these studies have arrived at the conclusion that international trade does help realising carbon load transfer between countries. Wyckoff and Roop (1994) find that on average, 13% of total emission of six of the largest OECD countries was embodied in manufactured imports. Peters and Hertwich (2007) show that around 5 Gt of CO2 is embodied in the international trade of goods and services, most of which flows from non-Annex I to Annex I countries. The similar conclusions are also achieved by other country-level studies, such as Peters and Hertwich (2006), which confirms that CO2 emission embodied in imports was 67% of Norway's domestic emission and around a half of this embodied pollution originates in developing countries, yet they represent only 10% of the value of Norwegian imports. Shui and Harriss (2006) also conclude that about 7%-14% of China's current CO2 emissions were result of producing exports for US consumers and US CO2 emission would have increased from 3% to 6% if the goods imported from China had been produced in the US.

The logic of the "carbon leakage" actually takes its origin from the "Pollution Haven" Hypothesis (PHH, Pethig, 1976; Chichilnisky, 1994; Copeland and Taylor, 1994). According to this hypothesis, under trade liberalization process, developed countries, facing more restrict environmental regulation, will lose their competitiveness in the polluting sectors. It will be their developing counterpart to pick up these market shares as their production faces less restrictive environmental regulations. Therefore, the relatively lax environmental regulation can be considered as a "comparative advantage" for the developing countries and we expect the developing economies to be gradually specialized in the polluting industries and finally to turn into a "pollution haven".

However, we believe it is important to distinguish between carbon leakage and "pollution haven". All situations leading to a surplus in balance of emission embodied in trade can be considered as carbon leakage, but a country can be called as "pollution haven" only if its comparative advantages are in pollution-intensive sectors.

Based on the case of China's manufacturing sectors, we investigate in this paper the co-existence of carbon leakage phenomenon and pollution haven hypothesis. For this purpose, we will base our study on an input-output model. This model allows us at first to calculate the balance of emission embodied in trade (BEET) and pollution terms of trade (PTT) for each manufacturing sector, with respect to the whole world and China's three biggest trade partners, the United States, Europe and Japan. This model also calculates *total* emission intensity for both export and import for different trade partners. These data are then used in a sector-level panel data (1996-2004) estimation explaining the determination of the comparative advantages for each sector.

This paper is organised as follows. Section 2 and 3 give separately literature review on the existing PHH and input-output analyses studies based on China's case. Section 4 presents the input-output model and explains the data sources. The principal results of the IO analysis will be presented in section 5. Econometrical analyses will presented in section 6, based on the 16 sectors panel data (1996-2004), to examine the determination of the revealed comparative advantages by both the factor endowment and environmental performance characteristics. Finally, we conclude in Section 7.

2. "Pollution Haven" Hypothesis literature

Most of the empirical studies on the low-regulation pollution haven, based exclusively on local pollution cases (SO2, PM, NOx, etc.), provide at best mixed conclusion. Only a restricted number of studies provide supportive evidence for "pollution haven" hypothesis.[3] More studies fail to prove the "Pollution Haven" Hypothesis.[4] Antweiler et al. (2001), followed by Cole et al. (2005), conclude that "either positive or negative, the environmental impact of trade should be small". Some studies even proved the contrary stories. (Sharfik and Bandyopadhyay, 1992; Grossman and Krueger, 1991; Wheeler, 2002) We can point out two aspects of reasons that can explain the ambiguity in the trade-environment relationship.

At first, Copeland and Taylor (1994, 1997) and Antweiler et al. (2001) remind us the comparative advantage of a country is determined by two aspects of characteristics of an economy: natural factor endowment and environmental regulation strictness. Although the relatively low income in a developing country prevents it from adopting strict environmental regulation, whether this developing country will turn into a "pollution haven" also depends on its factor endowment situation. Supposing pollution-intensive sectors are generally capital-intensive, Copeland and Taylor (1994, 1997) conclude that a developing country will be specialized in polluting industries only if its pollution compliance cost advantage is large enough to overcome its capital cost mark-up with respect to its developed trade-partners.

Secondly, as the Heckscher–Ohlin model, an underlying assumption of the "Pollution Haven"

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[3] Robinson (1988), Low and Yeat (1992); Hettige et al. (1992), Birdsall and Wheeler (1997), Suri and Chapman (1998), Xing and Kolstad (2002), Friedl and Getzner (2003) and Cole (2004).

[4] Bartik, 1985, 1988, 1989; Leonard, 1988; Friedman et al., 1992; Levison, 1992; Wheeler and Mody, 1992; Kalt, 1998; Tobey, 1990 Jaffe et al., 1995; Janicke et al.,1997; Van Beers and van den Bergh, 1997; Grether and de Melo, 1995; Gale and Mendez, 1998; etc.

hypothesis is equal technology level between trade partners. Based on this assumption, international trade allows countries to exchange their relatively abundant factors (either capital or labor in H-O model or environmental services in PHH) against their scarce factors. However, as suggested by the "Leontief paradoxal", it is possible that the quality of factors is different between trade partners, so a good can be labor-intensive in one country but capital-intensive in another. Similarly, we can also imagine the potential difference in production technologies and energy efficiency between countries to lead the production of one goods to be more polluting in one country than in another one. Xu and Song (2000) remind in their paper the potential differences in pollution intensity between Asian countries and the US and their impact on calculate of environmental service embodied in trade.

Some authors therefore propose to study content of pollution in trade instead of trade itself on sector level and examined its relationship with the sector-level specific environmental regulation difference between trade partners. One interesting previous study is Grether et al. (2005), in which the authors analyzed the determination factors for pollution content of imports for more than 50 countries over 1986-1996 through a Gravity model.

3. China-related emission embodied in trade studies based on input-output model

Since firstly used by Fieleke (1975), the Input-Output model has been frequently used to quantify the "environmental loading" of trade products: Wyckoff and Roop (1994) for 6 OECD countries; Kondo et al. (1998) for Japan, Lenzen (1998) for Australia; Munksgarrd et al. (2000) for Denmark and Machado et al. (2001) for Brazil, Peters and Hertwich (2006) for Norway, Lenzen et al. (2004) for Denmark, Hayami and Nakamura (2007) for bilateral trade between Canada and Japan, Aukerman et al. (2007a) for bilateral trade between Japan and US, Norman et al. (2007) for bilateral trade between US and Canada, etc.

Although IO analysis has been frequently applied to environmental analysis since 1990, its application on China's emission or energy embodied in trade only begins after 2000. Some very first studies only calculated emission embodied in export since to calculate emission embodied in import needs distinguishing production technology difference between China and its trade partners. Liu et al (2010) evaluated the energy embodied in trade in China during 1992-2005 and Weber et al. (2008) compute the CO2 emission emitted by production of export in China during 1987-2005. To include the emission embodied in import into consideration, some other studies use "import substitution" assumption that supposes the emission intensity of foreign production is equivalent to domestic production. The emission embodied in import calculated under this assumption is actually the emission "avoided" instead of the real emission emitted in the origin export country. Based on this assumption, Li et al (2007) calculated China's energy embodied in trade based on a single-country IO model for 1996-2004. To take into account the potential difference in carbon intensity between China and its trade partners, Pan et al (2008) use origin export country's emission rate to calculate the emission embodied in China's import. Some authors also use linked single-country model to include the foreign countries' IO tables and carbon intensity rate in carbon embodied in trade calculation. We can include the following studies into this group: Liu et al. (2010) for the bilateral trade between China and Japan, Shui and Harriss (2006) between China and US, Li and Hewitt (2008) between China and UK, Reinvang and Peters (2008) between China and Norway and finally Temurshoev (2006) bwteen China and US.

Most of these studies confirm that China experienced fast trade related emission increase.

While a few studies confirm China as a net importer of emission (such as Li et al., 2007), most of them concluded China as a net exporter. We believe the divergences in the conclusions of these studies result from the assumption about the carbon intensity and production structure of the trade partners. Figure 1 illustrates the carbon intensity difference between China and its most important trade partners during the period 1990-2006. Although China has enjoyed during past 15 years impressive carbon efficiency gains, its carbon emission intensity per unit of GDP is still 5 times higher than Canada, 3.9 times higher than US, 10 times higher than France and Japan and about 1.6 time higher than India. The big technological gap and production structure differences between China and its trade partners implies non-negligible bias in BEET calculated using China's emission intensity for import. The conclusion of Milner and Xu (2009) echoes well to this reasoning. They find China as a net carbon importer if the "avoided" emission of import is used in the calculation of BEET, but a net carbon exporter if the import part of emission is calculated as the emission emitted in origin export country.

The discussion about the potential technical and energy/pollution efficiency differences between China and its trade partners in the session 2 encourages us to use a linked single-region Input-Output model in our analysis. Such model allows us to obtain country and sector specific emission intensity, which is based on both structure and technological situation of each economy.

4. The I-O model

To assess the CO2 embodied in trade, the fundamental principle is to multiply, respectively, the *total* carbon intensity coefficients by foreign trade figures (export and import vectors). The utility of the IO analysis is to calculate these sector-specific *total* CO2 (energy) intensity coefficients which take into account for both the direct and indirect emission related to the production of one unit of final goods (Leontief and Ford, 1972).

Following Leontief (1970) and Miller and Blair (1985), the total output of one economy can be calculated as

$$x = (I - A^d)^{-1}y.$$

$(I - A^d)^{-1}$ is the N×N Leontief inverse with elements b_{ij} describing the amount of output generated in each domestic sector i for the production of one unit of final demand of sector j. x is an N×1 vector of gross outputs with elements x_i, i=1, 2, …,N, for each economic sector i, y is an N×1 vector of final demands with elements y_i, including household consumption, government consumption, investment, variation in stocks and finally export to the rest of the world (which can be further detailed according to export destination countries).

If we have the CO2 emission intensity coefficient matrix $\widehat{\Omega}$, the total embodied CO2 emission (direct plus indirect) for each of the sectors will be

$$f = \widehat{\Omega}x = \widehat{\Omega}(I - A^d)^{-1}x$$

Where f is an N×1 vector of CO2 emission volume with elements f_i and $\widehat{\Omega}$ is a N×N diagonal matrix, with elements on the diagonal z_{ij} (i=j) to be the CO2 emission intensity coefficient of sector i and the element of zero on the off-diagonal section.

Based on these equations, we know that China's CO2 emission embodied in export can be directly calculated by

$$f^x = \widehat{\Omega}(I - A^d)^{-1}exp$$

Here, *exp* is a N×1 vector of export volume, with element exp_i representing the value of the export realised by each sector i.

We can also apply this calculation on import, in this case, we obtain emission "avoided" by import for China,

$$f^m_{avoided} = \widehat{\Omega}(I - A^d)^{-1}imp.$$

Here, *imp* is an N×1 vector of export volume, with element imp_i representing the value of the import realised by China classified into each sector i.

As different countries can have totally different technical efficiency and intermediate input structure for the same final product, the emission "avoided" by import is not equal to the emission actually emitted by the import origin countries from its production activities. Considering that most of China's trade partners enjoy higher efficiency in carbon emission, we expect the real emission happening in import countries should be lower than the emission "avoided" by China. To measure the true pollution burden transfer described by the "carbon leakage" for China's international trade, we will use a *linked single-region IO model*.[5] In this model, national input-output tables of China and those of his trade partners will be *exogenously* linked with their bilateral trade data to calculate the true emission burden in China and his trade partners related to their bilateral trade.[6]

Therefore emission caused by the import of China from foreign country k can be calculated as:

$$x_k = (I - A^d_k)^{-1}y^{im}_k.$$

Here, y^{im}_k is a N×1 vector of import volume from country k to China, with element $y^{im}_{k,i}$ signifies detailed import for each sector i. A^d_k is domestic direct requirement matrix of country k. The emission embodied in import from country k to China can then be calculated by

$$f_k = \widehat{\Omega_k}(I - A^d_k)^{-1}y^{im}_k.$$

Here, f_k is a N×1 vector of carbon embodied in import from country k to China, with element $f_{k,i}$ signifies detailed carbon embodied in import for each sector i in country k. $\widehat{\Omega_k}$ is N×N diagonal matrix of CO2 emission intensity coefficient of country k.

Adding up emission embodied in import of sector i from all importing countries, we can

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[5] Hayami and Nakamura (2007) used this model to check the GHG emission embodied in trade between Canada and Japan.

[6] One shortcoming of the linked single-country model is that it does not include imported intermediate demand matrix (A^m) of each country and thus can only capture the last stage of an international supply chain of imports. For example, the imports of goods A from China to the US can in its turn induce some intermediate goods B's imports of China from Canada. However, the linked single-country model calculates the emission leakage from US to China by blindly assuming *all* the production process of goods A to be produced in China, which will have the tendency to over-estimate the emission leakage scale between these two countries. However, Lenzen et al. (2004) concluded with the case of Denmark that, excluding the above mentioned trade-related "feedback" loops causes relatively small bias, only about 1-4%. Facing the trade-off between heavy load of data requirement if we take into account the "feedback" loop into the import related emission calculation and the relatively small bias of the linked single-country model. We prefer to apply the linked single-country model in this paper.

obtain total emission embodied in import of sector i for China.

$$f^m = \sum_k f_k.$$

Once the emission embodied in both export and import for each sector are obtained, we can then calculate sector-level balance of Emission Embodied in trade (BEET), which is equal to emission embodied in export minus emission embodied in import. For a sector I, BEET>0 signifies an environmental trade surplus, the sector produces more pollution when participating the international trade. On contrary, BEET<0 signifies an emission trade deficit, for one sector, participating in international trade can lead to pollution reduction.

$$BEET_i = f_i^x - f_i^m$$

Another indicator that we can calculated is Pollution Terms of Trade (PTT, Antweiler 1996).

$$PTT_i = \frac{f_i^x / exp_i}{f_i^m / \sum_k imp_{i,k}}$$

PTT is the quotient of emission embodied in one unit of export over the emission embodied in one unit of import, PTT>1 means emission intensity in export embodies to be higher than that of import.

we can also calculated the avoided emission in import by multiplying the import data with China’s emission intensity coefficient, this can bring us another two indicators:

$$BEET_{avoided,i} = f_i^x - f_{avoided,i}^m$$

$$PTT_{avoided,i} = \frac{f_i^x / exp_i}{f_{avoided,i}^m / \sum_k imp_{i,k}}$$

5. Data sources

The IO analysis described in the last section requires three parts of data. The Input-Output table of China and that of its trade partners;[7]the bilateral trade data between China and its trade partners; and finally county- and sector-level data on energy consumption, output and carbon content of the different types of energies to impute the CO2 emission intensity coefficient matrix $\widehat{\Omega}$ for each country. To avoid the heavy data treatment load related to the big number of trade partners, in this paper, we divided the trade partners of China into four groups: the US, Japan, Europe and the rest of world. The total trade values with the first three groups of countries are over 55-60% of total import/export in China annually.

The IO tables for China, US, Japan and Europe (based on the IO table of the UK) in 1995, 2000 and 2005 are obtained from OECD IO tables sets (OECD, 2009). The mapping is based on the principle of keeping the sector classification as detailed as possible. In our calculation, the IO tables of the closest year are used to match with the other two parts of the data.

The sector level energy consumption and output data for China comes from “China Statistic

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[7] The detais in sector mapping and the final sector classification used in the IO analysis is given in Appendix of the paper.

Yearbook". The conversion of each type of energy combustion to CO2 emission intensity is done according to the directive explained in IPCC (2006). China's CO2 emission intensity used here is directly calculated from China's real energy consumption data.

Given the data availability and mapping difficulties, sector level CO2 emission intensities for the four groups of trade partners are converted from China's data, by taking care of difference in national level average carbon emission intensity between China and its trade partners. Taking the example of US, the emission intensity conversion factor $\lambda_{\frac{us}{chn}}$ for a certain year is:

$$\lambda_{\frac{us}{chn},t} = \frac{f_{us,t}}{f_{chn,t}} = \frac{CO2_{us,t} \big/ GDP_{us,t}}{CO2_{chn,t} \big/ GDP_{chn,t}}$$

Then for a specific sector i in year t in US, its carbon emission intensity coefficient will be:[8]

$$f_{us,i,t}=f_{chn,i,t} * \lambda_{\frac{us}{chn},t}$$

We also assume the emission intensity for the rest of the world is equal to that of China.

6. Calculation results from IO analysis

Table 1 gives the calculated results for emission embodied in export, in import, and the corresponding BEET and PTT indicators on national level for the period 1996-2004. As we can see, during this period, China stays as a net emission exporter, both in terms of absolute balance of real emission embodied in trade (positive values) and in terms of pollution terms of trade which measures the carbon intensity per unit of export with respect to import (value superior than 1).[9] Dynamically, although the absolute values of carbon balance illustrate an increasing trend during 1996-2004,[10] we observe a more general decreasing tendency in PTT value for the same period. This signifies that though the absolute scale of surplus in emission embodied in trade continues increasing, the gap between the carbon embodied in unit of export and that embodied in unit of import is decreasing, especially after 1999. This actually echoes to the rapid carbon intensity decreasing trends in China during the last decades, which was illustrated previously in Figure 1.

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[8] The underlying assumption for this conversion is that the foreign trade partners have the same sector-level energy consumption structure as China. Therefore the emission calculated under this assumption ignores potential energy consumption structure differences between China and its trade partner, can therefore lead to estimation bias. However, we believe such a proxy is still worthy. Until now, we find only one study analysing China's BEET with the rest of the world; this is Milner and Xu (2009). In their paper, to spread the calculation of BEET for China with the whole world, their linked single-country IO model suggests that all China's import origin countries share the same production and energy consumption structures as the US. Compared to this study, we believe our approach has following two advantages. Firstly, our study distinguishes the production structure and average energy efficiency between China's import origin countries, this can bring a measurement of BEET more close to the reality than the one calculated in Milner and Xu (2009), which implies the most pessimist situation for China by suggesting all trade partners of China to have the same energy efficiency and production structure as the US. Secondly, our pageper can also calculate the BEET for China with each of its principal trade partners: the US, Europe and Japan, which can be further used in the region-specific comparative advantage determination analyses.

[9] Except the BEET for year 1996 which is a small negative value.

[10] Except the short period between 2001 and 2002, during which we observe a slight decline in BEET values, This might be explained by the largely documented statistic missing in energy consumption data in China during these several years, when many very polluting small coal mines, officially shut-off and erased from the official statistics, still ran illegally to respond to the pressure of increase demand for energy of Chinese economy related to its entering to WTO.

We further calculate PTT for China's bilateral trade with the three principal trade partners, Japan, the United States and Europe. Given these countries' (region's) carbon efficiencies are significantly higher than China and world average level, it is reasonable to see that China's PTTs with respect to these three countries are significantly higher than its PTT with respect to the world as a whole. (c.f. Figure 2.a) The PTT with Japan is the highest among the three countries, followed by Europe. This corresponds to our general understanding of the superiority of Japan with respect to Europe in energy and carbon efficiency. The trade with US seems to have the lowest PTT among the three trade partners; this also corresponds to the fact that the US economy is more carbon intensive than Japan and Europe.

In Table 1 we also report the BEET and PTT calculated from the "avoided" emission. These two terms compare the emission embodied in export with the emission "avoided" in domestic production through imports. As China is less carbon efficient than its principal trade partners, the carbon surplus calculated from the "avoided" emission is smaller than the real BEET. More interesting, the $PTT_{avoided}$, which compares carbon embodied in one unit of export with carbon avoided by one unit of import, gives a series of value smaller than one. This actually signifies the fact that, for China, each dollar's export actually involves less pollution than the carbon avoided by each dollar's import. This reveals the fact that China is actually an exporter of less-polluting goods and an importer of more pollution-intensive ones. The same pattern of evolution can also be observed from the $PTT_{avoided}$ calculated from the bilateral trade data, whose values are all below 1. (c.f. Figure 2.b) Another interesting finding is that China's import from its trade partners can actually reduce the world level carbon burden since China's emission avoided by import (first line of Table 2) is always higher than the emission embodied in its import (the second line of Table 1).

Table 2 illustrates the details about trade and trade-related embodied emission situation in year 2004 for the 16 manufacturing sectors. We can see that although the trade surplus in absolute monetary values indicates that only 9 over 16 sectors export more than import, all sectors actually have surplus in terms of carbon embodied in trade. This is because the final result of BEET is dependent on both the trade surplus and the emission intensity difference in export vs. import. Even if a sector has a trade deficit, if its emission intensity of export is sufficiently higher than that of import, BEET can still be positive.

Table 2 also reports PTT for each sector in this table. We find only three sectors (nonmental product, other metal products and plastics and rubber products) have a PTT smaller than 1, which means a better emission efficiency in export than that in import. For most of the light industries, where China enjoys significant trade surplus (textile, wood product, electronic equipment and machinery and equipment), they also have a PTT higher than one, which means their emission efficiency in export is actually lower than that in import. We can conclude that export from China to the rest of the world has the tendency to increase the global carbon emission volume.

Another interesting finding from Table 2 is that, horizontally compared, almost all the sectors in which China has a trade surplus have relatively smaller PTT, at the same time, the sectors having relatively larger PTT present very often trade deficit. This reveals that China is more specialised in cleaner sectors, which are often light industry with high labor intensity. Figure 3 recapitulates this finding by illustrating negative correlation between PTT and trade balance plotted with the 16 pairs of data listed in Table 2. Apparently, a higher trade surplus is in general associated with lower PTT, although few PT<1.

Dynamically speaking, most of the sectors seem to experience PTT reduction during the period of 1996-2004 (c.f. the PTT variation column in Table 2). This reveals general tendency of technology and production efficiency improvement in China compared with its trade partners. This decreasing tendency is, however, not shared by all sectors. Pharmaceutical chemical product, transportation equipment, and rubber and plastic products have experienced since 1996 the tendency of PTT increasing. These should be explained by sectors' specific characteristics.

7. Pollution haven hypothesis investigation

Until now, our I-O analyses reveal China as less carbon efficient but with trade surplus more concentrated in relatively less polluting sectors. The surplus of BEET in most of the sectors is due to its big trade surplus and its higher emission intensity compared to its trade partners.

To further deepen our understanding on this issue, in this sector, we use the sector level panel data to investigate the determinant factors for China's international trade patterns, with a particular attention given to the verification of factor endowment hypothesis (FEH) and pollution haven hypothesis (PHH) based comparative advantages in China.

The estimation function used in this paper is:

$$RSCA_{it} = \alpha + \beta_1 PHH_{it} + \beta_2 FEH_{it} + \beta_3 tariff_{it} + \beta_4 R\&D_{it} + \beta_5\, size_{it} + v\ time\ dummy + u_i + \varepsilon_{it} \tag{1}$$

Here the subscript i means sector and t means year. The dependant variable is the index of comparative advantage called the Revealed Symmetric Comparative Advantages (RSCA, Laursen, 1998). This indicator is an adaption of the initial revealed comparative advantage index (RCA) of Balassa (1965, 1979 and 1986). The original indicator RCA at year t is calculated as:

$$RCA_{it} = \frac{x_{it}/\sum_i x_{it}}{x_{w,it}/\sum_j x_{w,it}}.$$ [11]

Laursen (1998) adapted the RCA into RSCA, by the following simple transformation.

$$RSCA_{it} = \frac{RCA_{it} - 1}{RCA_{it} + 1}$$

The advantage of this adapted indicator is its symmetry, after transformation, the value of RSCA is between -1 to +1, with the central value at zero. When $RSCA_{jt}$ is lower than 0 (a negative value between -1 and 0), the sector i in year t has a comparative disadvantage and when $RSCA_{jt}$ is higher than 0 (a positive value between 0 and +1), the sector has a comparative advantage.

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[11] So the RCA measures the part of export of the sector i in total export of China compared to the export of the same sector in the world to the total export of the world. A larger RCA value means the sector i in China has more comparative advantage. This revealed comparative advantage indicator has the value varying between 0 to +∞, when the value is between 0-1, it means no comparative advantage and when the value is over 1 till +∞, it means the possession of comparative advantage.

For comparative advantage determinants, we firstly consider two central hypotheses: one is the pollution haven hypothesis (PHH) and another is the factor endowment hypothesis (FEH).

The pollution haven hypothesis suggests that China as a developing country may have comparative advantages in pollution-intensive sectors; since China's relatively low per capita income level does not permit it to attach the same level of importance on environmental quality as its principal trade partners. We therefore use total carbon-intensity per unit of import as independent variable (*emiM*).[12] A positive coefficient for this variable, signifying a pollution-intensive sector to have more tendencies to dislocate its production to China, therefore forms higher comparative advantage in this country. Based on this reasoning, we should consider a significant positive coefficient as proof for validation of the pollution haven hypothesis.

For the factor endowment hypothesis (FEH), we use capital intensive ratio *(K/L)* as representative measurement. This measurement has been largely used in trade-environment nexus studies, including the most important ones as Antweiler et al. (2001) and Cole and Elliott (2003), etc. Based on the H-O model, we know that for a country as China with abundant endowment of cheap labour force, it should have comparative advantage in labour-intensive sectors. We therefore expect negative coefficient for this variable, which relate the lower value of K/L ratio in a sector to a higher RSCA indicator.

We further include the following explicative variables into the comparative advantage determination function. The research and development (R&D), which is measured by the percentage of R&D expenditure in each sector in total value-added of the corresponding sector; the average size of enterprises belonging to the same sector, calculated by the total gross output divided by total number of enterprises belonging to the corresponding sector; and also the tariff (ad valorem) which measures the tax rate per 100 dollar's import. We generally believe active research and development activities, larger enterprise scale and high ad valorem tariff should be beneficiary for comparative advantage formation, so we expect positive coefficients for these three independent variables.[13] To capture potential common tendency in comparative advantage evolution between sectors, we also included yearly specific dummies. We expect to interpret common evolution trends of the comparative advantage of different sectors by coefficient value of these dummies. Table 3 gives detailed descriptive statistics for the variables.

Tables 4 and 5 report the estimation results based on the equation (1). Table 4 uses import emission intensity (emiM) as measurement of PHH factor and K/L as FEH factor. Considering panel data's bi-dimensional information: the time-dimension one measuring dynamic evolution of the data belonging to same group (within difference) and the horizontal one measuring relative difference between data of the different groups during the same periods (between difference), we also transform the data for emiX and K/L into within difference (with suffix "dynamic") and between difference (with suffix "relative"). The related results are reported in Tables 5.

In these two tables, we estimate not only the RSCA for China's international trade as a whole,

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[12] The reason for not using total emission intensity of export or PTT is due to the consideration that the formation of the pollution haven is in general pushed by the demand side forces: the restrictive environmental protection regulation in the developed country forces the polluting sectors to lose their comparative advantages with respect to the developing countries as China. So from the point of view of China, the formation of the comparative advantages in these polluting sectors are more related to the high emission intensity of its trade partners instead of its own pollution performance.

[13] The choice of the three variables is based on the data availability.

but also the RSCA for China's bilateral trade with the United State (US), Japan and Europe Union (Europe). In group-level estimations, the emiM is regionally specific. For most estimations, Random Effect models are preferred to Fixed Effect ones. Considering the panel data has 9 years, we use panel data GLS estimator with AR(1) correction in our analysis. Tables 4 and 5 only report the results obtained in GLS estimation with AR(1) correction, since the comparison shows that between different estimations, the variables report stable coefficients.

The results in Table 4 report uniformly negative coefficients for emiM. This is true for both total international trade and bilateral trade with the three principal trade partners, although only Total and Europe columns report statistically significant negative coefficients. This finding implies that sectors with lower import emission intensity have in general higher comparative advantage. The coefficients found for variable K/L are more uniform, both in coefficients' signs and their significance. Their negative coefficients reveal the fact that China's comparative advantage is in labor-intensive sectors. Antweiler et al. (2001) suggests the comparative advantage of a country is a final result of force contrast between PHH and FEH. For the case of China, the estimation results of Tables 4 seems to confirm that it is still the factor endowment comparative advantage that plays dominating role in determination of the comparative advantage, so the specialization of China in world production chain is still more pronounced in less-polluting labor-intensive sectors.

Our estimation results report negative and insignificant coefficients for R&D, except for the bilateral trade with the US. This finding seems to reveals that the investment in research and development activities does not necessarily promote China's comparative advantages. To express in another way, China's comparative advantages currently are not in the technology intensive sectors. The US seems to be currently the only country that is interested in the export from China's newly emergent high-tech sectors.

We do not find coherent and significant coefficients for average enterprise size (size) and the tariff ad valorem (tariff) variables, except for the bilateral trade with Japan, where we find positive and significant coefficient for the variable *tariff*. This signifies the practice of import tariff can foster or improve the comparative advantage of China's sector with respect to his counter partner in Japan. This might be explained by the highly mutual interdependence between China and Japan, which makes the usage of tariff an efficient trade barriers for China to substitute imports and/or to promote exports in certain sectors, where the integration between the two countries are relatively high.

Our estimations in general obtain significant time dummies' coefficients, whose value presents a decreasing tendency which corresponds well to the evolution tendency of China's RSCA. Figure 4 reports the comparison of RSCA in 1996 and in 2004 for all 16 manufacturing sectors. Some previously very active export sectors, such as textile, wearing apparel and leather products, rubber and plastic products experienced significant reduction in their comparative advantages. At the same time, some other previously importing sectors increased their import dependency owing to the improvement of the living conditions of the Chinese people, such as food, tobacco and beverage, petrol chemical, coke and nuclear energy, chemical product, pharmaceutical products. While at the same time, we observe the cases of comparative advantage improvement (wood and timber products, other metal products, machinery and equipment, electronic equipment) or the decrease of the comparative disadvantages (paper product, transport equipment) in other sectors, their evolution scale are relatively small.

The estimations reported in Table 5 distinguish within and between difference in PHH and FEH variables. In general, the distinction between these two dimensions' information contributes to the improvement of explanation power of the original model (1), where the Wald test gives significantly larger value than that in Table 4 and enriches to certain sense the interpretation of the determination roles of PHH and FEH in China's comparative advantage. When the emiM-relative keeps reporting a negative correlation with RSCA, which continues to confirm China's comparative advantages in less polluting labor-intensive sectors; the significant and positive coefficients found for emiM-dynamic (at least for Europe) seems to reveals that increase of emiM actually leads to an reinforcement of comparative advantage in China's manufacturing sectors. The reasoning to explain this result is that, even for a less-polluting industry, although the pollution problem is less serious than that for the polluting industries, the pollution as a problem still exists. An increase in emission intensity in import (emiM) in the developed trade partner countries will lead China's comparative advantage to increase. We can consider this finding as evidence supporting Pollution Haven Hypothesis in China.

Our estimation attribute to the variable *K/L-dynamic* in most cases statistically significant positive coefficients, this actually reveals another facet of the measurement K/L. The capital intensity ratio K/L has been used in the past very often in environment-trade nexus analysis. Some of studies, using K/L to explain pollution indicators, reported negative coefficients (Dinda, 2001, He, 2009, etc.) One common assumption to explain this positive coefficient is that K/L can also be a measurement for the advancement of the technology in a sector. For a given sector, the dynamic increase in capital intensity actually measures the progress in production technology instead of a measurement of factor endowment intensity, so it is now easy to understand the positive coefficients found for the *K/L-dynamic*: production technology progress contributes significantly to formation and/or improvement of comparative advantages, this is true for both capital-intensive and labor-intensive sectors.

8. Conclusion

Based on 16 manufacturing-sector single-country linked Input-Output model, in this paper we firstly calculated the balance of emission embodied in trade (BEET) and pollution trade terms (PTT) for China's international trade with rest of the world and its principal trade partners (Japan, the US and European Union) in 16 manufacturing sectors for the period 1996-2004. Our results report positive BEET values and PTTs larger than 1 for most of the sectors and for the whole China, which confirms China as a net emission exporter via its international trade, either in absolute value or in relative intensity comparison. However, the calculation also reported the values less than one for the avoided PTT, this reveals that China's exports are in fact more often concentrated in relatively less-polluting sectors.

In the second part of our analysis, we compiled sector-level panel data for the period covered by the IO analysis to estimate the determination function for China's sector-level comparative advantage. In this step the total emission intensity of import (emiM) directly calculated from the IO analysis and capital intensity were included as the two most essential determinants of comparative advantage. The coefficients found for both determinants confirm that China actually has more comparative advantages in less polluting labour-intensive sector. However, once we further decomposed the emiM and K/L variables into horizontal relative dimension and vertical dynamic evolutional dimension, we also found that emiM dynamic and K/L dynamic are positively related to the comparative advantage indicators. This actually reveals the fact that, either pollution-intensive or less pollution-intensive, a sector experiencing a pollution intensity increase in foreign countries can expect its comparative advantage in China to increase. We regarded this finding as evidence supporting the existence of the Pollution Haven Hypothesis for the case of China, although its impacts are currently totally cancelled off by the Factor-Endowment based comparative advantage. For the K/L-dynamic, its positive correlation with sector-level comparative advantage indicator can be interpreted as an effect of technological progress: either labour-intensive or capital–intensive sector, an increase in its K/L during the time signifies increase in technical efficiency of the production; this can in its turn reinforce its comparative advantage.

Summarizing the findings of this paper, one important conclusion is that a net emission exporter is not necessarily a pollution haven. Even a country exporting principally in less-polluting sectors can also have a positive BEET. This is because the BEET is a final result of trade-surplus and pollution terms of trade. The principal reason for China to have surplus in emission embodied in trade is due to the fact that China has higher emission intensity in these less polluting sectors than its trade partners. Our finding also reveals the fact that until now, the organisation of international production division is still based on traditional factor endowment hypothesis, the pollution haven hypothesis only plays a very marginal role.

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Figure 1. Carbon intensity gaps between China and its main trade partners (comptetitor)

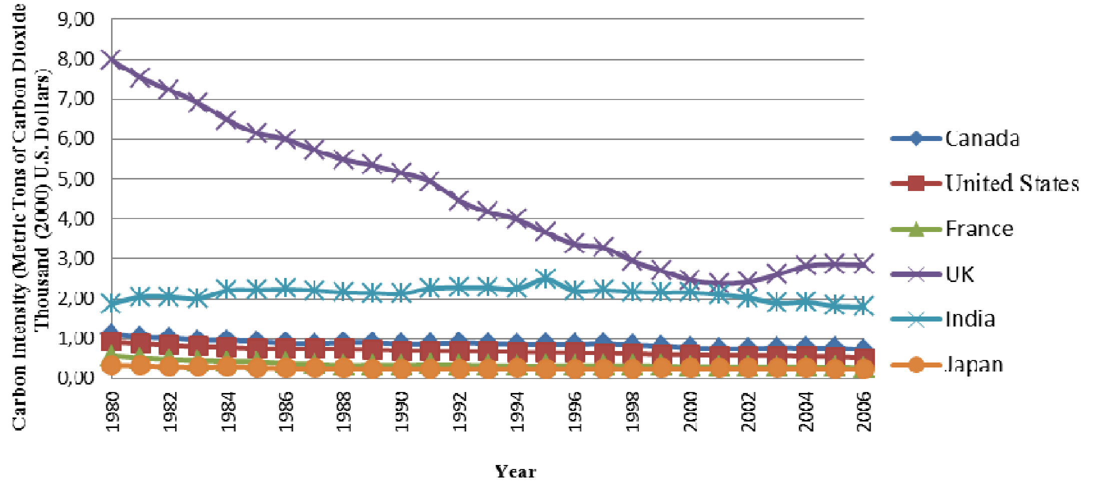


Figure 2.a China's Pollution terms of trade with respect to its principal trade partners

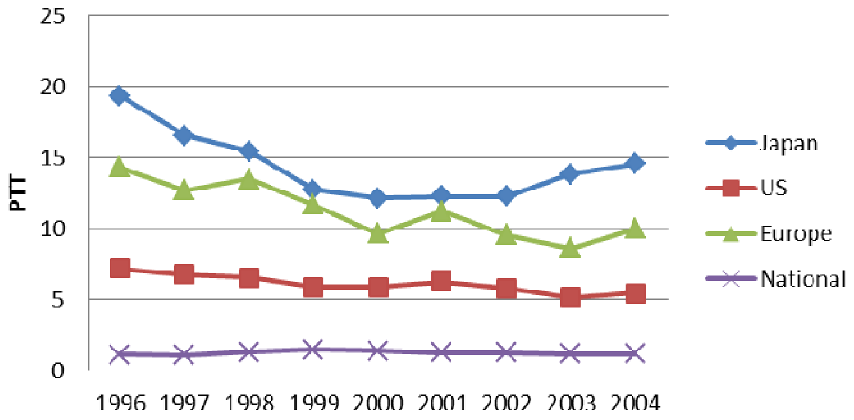
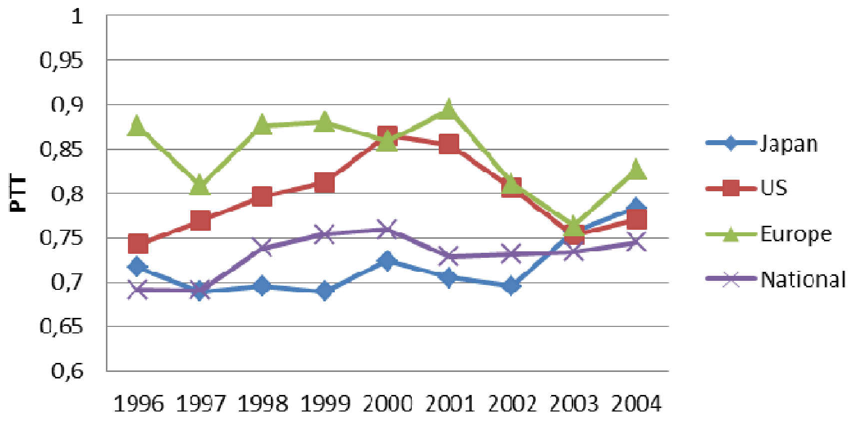


Figure 2.b China's avoided pollution terms of trade with respect to its principal tade partners



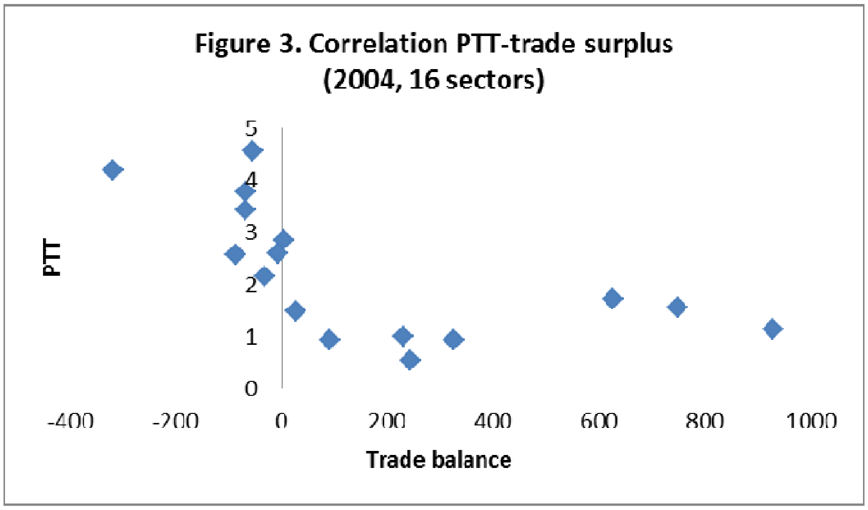


Figure 3. Correlation PTT-trade surplus (2004, 16 sectors)

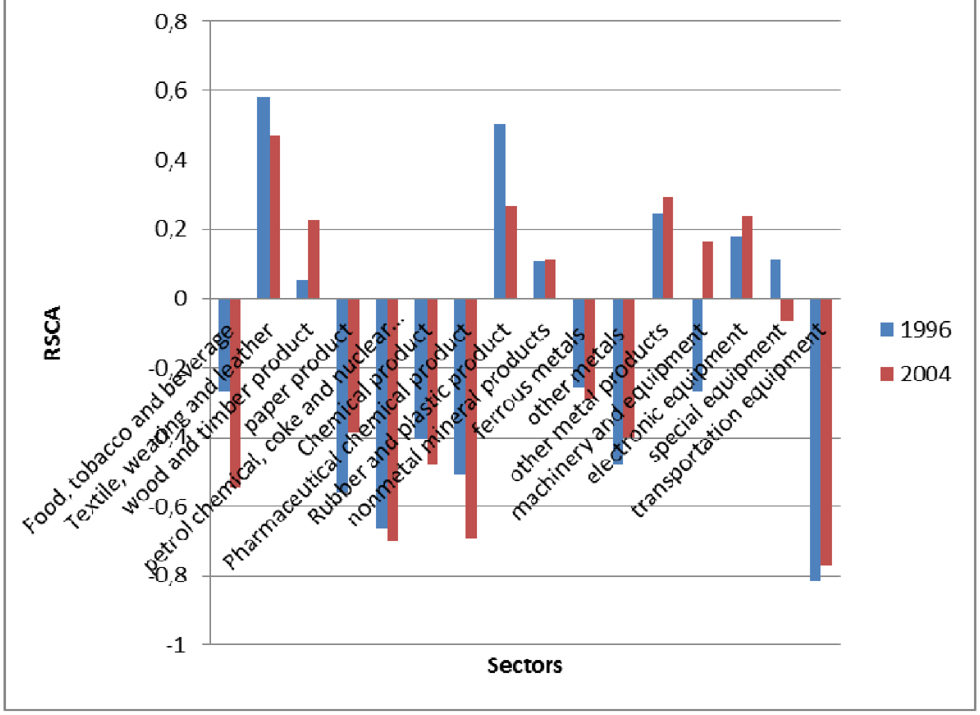


Figure 4. Evolution of RSCA of the 16 manufacturing sectors between 1996-2004

Table 1. National level and bilateral trade related embodied Carbon

	1996	1997	1998	1999	2000	2001	2002	2003	2004
Carbon embodied in Import	373605	363080	284243	258925	282743	259338	300994	404142	462108
Carbon avoided by import	612573	590486	499705	509930	517522	458862	516966	644604	748133
Emission embodied in export	609852	629475	621076	704963	727785	606376	652550	757104	926384
BEET	236247	266395	336834	446038	445043	347038	351556	352961	464276
BEET(avoided)	-2721	38989	121371	195033	210263	147513	135584	112500	178251
PTT	1.13	1.12	1.30	1.48	1.39	1.29	1.26	1.17	1.21
PTT(avoided)	0.69	0.69	0.74	0.75	0.76	0.73	0.73	0.73	0.74

Table 2. Emission embodied in trade for 16 manufacturing sectors in 2004

	carbon embodied in export	carbon embodied in import	trade surplus (export-import)	BEET	PTT	PTT variation with respect to 1996
	million tons	million tons	million USD	million tons		
Food, tobacco and beverage	49	25	27.07	23.42	1.48	-12.81
Textile, wearing apparel and leather products	463	82	929.63	381.21	1.13	-7.02
wood and timber product	68	6	230.17	61.57	1.01	-5.44
paper product	213	90	-7.14	123.38	2.61	-11.77
petrol chemical, coke and nuclear energy	3499	2098	-53.42	1401.65	4.57	-15.66
Chemical product	1672	1087	-318.00	585.03	4.20	3.38
Pharmaceutical chemical product	27	9	4.12	18.07	2.85	108.76
Rubber and plastic product	109	25	243.85	84.52	0.53	5.85
nonmetal mineral products	777	177	92.47	600.89	0.94	-20.18
ferrous metals	1794	743	-69.00	1051.62	3.78	11.71
other metals	353	190	-68.74	163.29	3.44	-2.83
other metal products	50	8	326.05	42.11	0.93	-33.15
machinery and equipment	79	27	626.00	52.72	1.71	-35.60
electronic equipment	37	14	750.00	23.07	1.56	-14.66
special equipment	38	20	-31.00	18.02	2.17	-19.25
transportation equipment	35	23	-86.00	12.20	2.57	18.72
total	9264	4621	2596.06	4642.76	1.21	6.32

Table 3. Statistics Descriptive

Variable	description	Obs	Mean	Std. Dev.	Min	Max
RSCA	Revealed Symmetric Comparative Advantage	144	-0.146	0.402	-0.817	0.581
PTT	Pollution terms of trade	144	2.452	1.433	0.500	6.900
emiM	total emission intensity for each dollar's import (ton/100US$)	144	3.2E-03	6.7E-03	1.0E-05	4.0E-02
K/L	K/L (10000 Yuan/person)	144	0.099	0.039	0.037	0.230
R&D	RD/total VA	144	0.018	0.018	0.001	0.077
size	average value added per enterprise (10 million Yuan)	144	0.184	0.198	0.009	0.984
tariff	tariff ad valorem (100 US$)	144	0.016	0.010	0.005	0.057
emiM_relative	between difference of emiM with respect to national average	144	-2.2E-11	6.6E-03	-4.3E-03	3.5E-02
emiM_dynamic	within difference of emiM with respect to sector average	144	2.5E-11	1.7E-03	-7.0E-03	1.3E-02
RSCA_us	Revealed Symmetric Comparative Advantage for bilateral trade with US	144	-0.184	0.462	-0.911	0.637
emiM_us	Pollution terms of trade for bilateral trade with US	144	1.1E-03	2.0E-03	3.4E-06	9.3E-03
emiM_relative_us	between difference of emiM with respect to national average for bilateral trade with US	144	4.9E-12	2.0E-03	-1.4E-03	8.0E-03
emiM_dynamic_us	within difference of emiM with respect to sector average for bilateral trade with US	144	-1.3E-11	6.8E-04	-4.0E-03	3.5E-03
RSCA_japan	Revealed Symmetric Comparative Advantage for bilateral trade with Japan	144	-0.142	0.394	-0.817	0.623
emiM _japan	Pollution terms of trade for bilateral trade with Japan	144	3.6E-04	7.7E-04	1.1E-06	4.4E-03
emiM _relative_japan	between difference of emiM with respect to national average for bilateral trade with Japan	144	-2.02e-12	.0007667	-.0004637	.003874
emiM _dynamic_japan	within difference of emiM with respect to sector average for bilateral trade with Japan	144	-6.5E-13	1.9E-04	-1.0E-03	1.2E-03
RSCA_europe	Revealed Symmetric Comparative Advantage for bilateral trade with Europe	144	-0.156	0.415	-0.955	0.522
emiM _europe	Pollution terms of trade for bilateral trade with Europe	144	5.5E-04	9.6E-04	2.4E-06	5.1E-03
emiM _relative_europe	between difference of emiM with respect to national average for bilateral trade with Europe	144	1.6E-12	9.6E-04	-6.9E-04	4.5E-03
emiM _dynamic_europe	within difference of emiM with respect to sector average for bilateral trade with Europe	144	-3.7E-12	2.4E-04	-1.2E-03	1.3E-03

Table 4. Determinants of Revealed Symmetrical Comparative Advantages (RSCA)

	Total	**US**	**Japan**	**Europe**
emiM	-6.888	-8.186	-4.667	-66.245
	(2.36)**	(0.84)	(0.14)	(2.37)**
KL	-3.381	-3.461	-2.143	-6.889
	(2.40)**	(2.01)**	(1.27)	(3.56)***
R&D	-0.678	0.306	-0.656	-1.901
	(0.78)	(0.29)	(0.62)	(1.50)
size	0.087	-0.095	-0.057	0.247
	(0.40)	(0.37)	(0.21)	(0.81)
tariff	2.748	0.933	10.167	-1.820
	(0.98)	(0.27)	(3.13)***	(0.52)
year1996	0.025	0.016	-0.247	0.387
	(2.67)***	(2.28)**	(2.76)***	(2.94)***
year1997	0.058	0.012	-0.137	0.373
	(2.54)**	(2.48)**	(2.03)**	(3.22)***
year1998	0.099	0.044	-0.092	0.417
	(2.33)**	(2.42)**	(1.79)*	(3.09)***
year1999	0.134	0.169	-0.086	0.612
	(2.16)**	(1.47)	(1.91)*	(1.69)*
year2000	0.173	0.209	-0.092	0.624
	(1.88)*	(1.21)	(2.17)**	(1.73)*
year2001	0.177	0.220	-0.091	0.601
	(2.36)**	(1.40)	(2.79)***	(2.57)**
year2002	0.219	0.216	-0.020	0.671
	(2.25)**	(1.97)**	(2.43)**	(2.28)**
year2003	0.269	0.284	0.047	0.744
	(1.81)*	(1.16)	(1.84)*	(1.66)*
year2004	0.319	0.323	0.108	0.808
	(1.75)*	(1.45)	(0.50)	(3.37)***
Breusch-Pagan	467.21 (0.000)	438.29 (0.000)	389.45 (0.000)	338.88 (0.000)
Rho (AR1)	0.9084	0.9104	1.1762	0.9440
Baltagi-Wu LBI[1]	0.85	0.98	0.89	0.94
Wald Chi2	20.60 (0.08)	40.08 (0.00)	24.86 (0.02)	67.45 (0.00)
Observations	144	144	144	144
Number of obs	16	16	16	16

Note 1: this is the autocorrelation test for the residuals obtained from the panel data estimations without treating AR(1).

Table 5. Determinants of Revealed Symmetrical Comparative Advantages (RSCA)

	Total	US	Japan	Europe
emiM-relative	-6.777	-11.009	-5.877	-134.407
	(1.02)	(0.38)	(0.09)	(2.35)**
emiM-dynamic	4.094	16.056	29.102	156.996
	(0.55)	(0.54)	(0.41)	(2.56)**
KL-relative	-8.793	-10.537	-5.688	-9.531
	(4.49)***	(4.22)***	(2.49)**	(3.95)***
KL-dynamic	8.156	11.167	6.142	8.655
	(3.84)***	(4.22)***	(2.48)**	(3.30)***
R&D	-0.215	0.853	-0.188	-1.308
	(0.25)	(0.95)	(0.18)	(1.28)
size	0.202	0.023	-0.014	0.272
	(0.95)	(0.10)	(0.05)	(1.03)
tariff	1.532	-0.543	9.032	-2.174
	(0.57)	(0.17)	(2.84)***	(0.66)
year1996	0.114	0.245	-0.129	0.248
	(3.63)***	(4.01)***	(1.66)*	(3.66)***
year1997	0.107	0.180	-0.052	0.201
	(3.82)***	(3.97)***	(2.10)**	(3.69)***
year1998	-0.016	0.013	-0.122	0.011
	(3.73)***	(3.82)***	(2.07)**	(3.38)***
year1999	-0.075	0.004	-0.189	0.056
	(3.84)***	(4.19)***	(1.95)*	(4.01)***
year2000	-0.159	-0.119	-0.287	-0.072
	(3.92)***	(4.23)***	(1.67)*	(3.99)***
year2001	-0.264	-0.245	-0.358	-0.239
	(3.79)***	(4.25)***	(1.47)	(3.56)***
year2002	-0.376	-0.442	-0.396	-0.352
	(3.72)***	(3.69)***	(1.60)	(3.72)***
year2003	-0.506	-0.590	-0.457	-0.497
	(3.71)***	(4.34)***	(1.68)*	(4.07)***
year2004	-0.656	-0.803	-0.538	-0.698
	(4.84)***	(4.78)***	(3.37)***	(4.19)***
Breusch-Pagan	470.12 (0.00)	476.63 (0.00)	390.43 (0.00)	371.83 (0.00)
Rho (AR1)	0.90	0.93	0.89	0.91
Baltagi-Wu LBI[1]	0.86	0.98	1.18	0.94
Wald Chi2	41.66 (0.00)	70.99 (0.00)	33.24 (0.00)	99.45 (0.00)
Observations	144	144	144	144
Number of obs	16	16	16	16

Note 1: this is the autocorrelation test for the residuals obtained from the panel data estimations without treating AR(1).