The Pollution Content in China's Trade

Preliminary version
Authors: Fangya Xu* and Chris Milner
August 2008

Abstract

In consideration of China's enormous trade volumes since opening up and huge trade surplus especially with the developed countries, it is worried that the environment is sacrificed in the process of trade liberalization in China. Employing the environmental input-output analysis, this paper attempts to investigate whether international trade aggravates the environmental issues. Comparing pollution actually embodied in exports and pollution avoided by importing, we find that (1) China surprisingly imports more "pollution embodiment" than its imports regardless of its enormous trade surplus in most of the IO years, and (2) China's exports are consistently cleaner than its imports. Further projection for recent years also shows that even without technological progress the trade mix (composition effect) will not change the fact that China gains environmentally from international trade in terms of the air pollutants in this study. When Japanese IO table is used to represent China's trading partners, the results are completely reversed indicating China's heavy dependence on coal for energy as well as its relatively lagged production technologies.

1. Introduction

The environment is highly related to the economy and the economic performance. However, in most conventional comparative advantage frameworks especially those of neoclassical ones, the role of the environment had been completely ignored. With rising global awareness on climate change, industrial pollution, species extinction and human welfare, the importance of the environment in accommodating production as well as in assimilating pollution is increasingly recognized and examined. As Leontief (1970) states, "frequently unnoticed and too often disregarded, undesirable by-

* Correspondence to: Fangya Xu, School of Economics, University Park, University of Nottingham, NG7 2RD UK.
E-mail: lexfx2@nottingham.ac.uk

products as well as certain valuable but unpaid-for natural inputs are linked directly to the network of physical relationships that govern the day-to-day operations of an economic system.” The increasing magnitude of international trade combined with the upsurge of foreign direct investment also triggers the concern over economic welfare across borders. Some studies (GATT, 1971; D’Arge and Kneese, 1972; Pethig 1976; Copeland and Taylor, 2003; Considine and Larson, 2004) have modelled the environment or environmental policy as a factor affecting production and serves as a determinant of comparative advantage.

Based on the theories of comparative advantage, two related hypotheses have been proposed in predicting a country’s trade pattern. The Pollution Haven Hypothesis (PHH thereafter) suggests that developing countries with relative laxer environmental regulations could gain advantage in producing dirty goods and become pollution havens for dirty industries migrating from developed countries. The Factor Endowment Hypothesis (FEH thereafter) predicts that developed countries may still have comparative advantage in producing dirty goods since polluting industries depend greatly on physical capital and human capital. Numerous studies (Grossman and Krueger, 1993; Mani and Wheeler, 1997; Cole et al, 2004) have been carried out to investigate these two hypotheses. The empirical results are quite mixed. However, as Copeland and Taylor (2003) emphasize, these two hypotheses do not work against each other; as a mater of fact, both motives have their merits in determining the trade pattern. The question remains as what strengths they have and which dominates. A cross-industry study for the U.S. by Cole et al (2004) found that while environmental stringency (proxied by pollution abatement costs) is a statistically significant negative determinant of revealed comparative advantage, factor intensities seem to play a more important role in determining specialization in the US dirty industries. To sum up, a strong form pollution haven hypothesis is not supported by most of the literature but a weak form pollution haven effect has been identified in a few studies.

As global concern over the environment continues to grow, many of the most frequently mentioned greenhouse gases (GHG thereafter) reduction policies such as taxes, tradable permits, and regulations will make the generation of these gases more costly, especially in developed countries. A generalization from the PHH implies that with relatively laxer environmental regulations China has a tendency to develop and accommodate dirty industries. As China involves itself to a greater extent in international trade, it is suspected that the environment is sacrificed in order for China to become wealthier. However, China is relatively scarce in capital stock compared to its major trading partners (mainly OECD countries). According to the FEH, there is possibility for China to specialize in clean (labour intensive) goods instead.

In this study, we don't test the two hypotheses in regressions which are becoming typical in the study of trade and the environment; instead we will look at the environmental consequences of international trade in China. We question whether the pollution embodied in China's exports exceeds that of the imports and whether China's exports are more pollution intensive than its imports as the PHH implies.

Under the common technology assumption, we find that not only does China avoid more pollution by importing than exporting but also China's exports appear to be cleaner than imports in terms of pollution intensity. The results are confirmed by sensitivity checks. Fixing the technology matrix, the projection of pollution embodiment in trade for recent years seems to confirm that trade mix (composition effect) is good for China's environment in terms of both the absolute and relative pollution embodiment in exports and imports. However, the results based on heterogeneous technologies show that the actual pollution embodiment in China's exports is greater than China's imports and that Chinese exports are much dirtier.

The remaining of the paper is organized as follows: section 2 provides a summary of literature review on measuring pollution content in international trade; the framework of the Leontief-type model and alternative assumptions are described in section 3; section 4 presents the data and gives out the findings; conclusions and caveats can be found in section 5.

2. Literature review

Trade can be either conceived as the overt exchange of goods suggested by traditional theories or as the exchange of the services of production factors. Vanek (1968) introduced the concept of the factor content of trade which involves mainly labour input and capital input. Accordingly, the input of environmental factors or in other words the output of pollutants in producing a good is usually termed as the "pollution content" or "pollution embodiment" in many recent studies.

In the process of globalization, international trade is increasingly playing a role in forging an economy's structure; the more open the economy is, the more influential international trade has on the economy. Pollution embodied in international trade has provoked intensive awareness in this regard. Since tt is almost impossible to cover the huge existing literature[1] on the relationship of trade and the environment, we only select a small fraction of studies which are closely related to this paper.

There are a number of ways to estimate the pollution embodiment in production/trade which vary in accuracy and level of aggregation. We group them into two broad schools according to the criteria whether the study catches only the direct pollution emissions or the overall effect (sometimes termed as the life-cycle effect).

2.1 Simple measurement

A few studies have taken a relatively simple form of measurement by multiplying the industrial emission intensities with industrial production/trade volume.

Muradian et al. (2001) provided an insightful picture of the pollution embodiment in trade for 18 industrialized countries from 1976 to 1994 (in discontinuous years). Using the emissions intensities of five air pollutants from the Industrial Pollution Projection System (IIPS) database, the authors find that in the 1990s the industrialised world's embodied emissions in imports tend to be larger than that in exports. Also by investigating further into individual industrial countries and individual pollutants, the authors find different patterns of the evolution of environmental terms of trade.

Again using IPPS coefficients, Grether et al (2005) (work in progress) measure the amount of pollution emitted per dollar of imports. The authors explore, in the gravity framework, the determinants of pollution content in trade as well as the influential factors of trade specialization for 16 different pollutants in more than 50 countries

[1] For comprehensive reviews on this topic, see Dean, 2001; Copeland and Taylor, 2004; UNEP, IISD, IISD, 2005.

over the 1986-1996 periods. Using CO_2 emissions per dollar of GDP as preferred proxy for environmental stringency, their results reveal both a factor endowment effect and a pollution haven effect (with larger elasticity). However, data limitation greatly restrains the results since IPPS coefficients they use are only available for 1987 for US industries.

Using trade flow data with the country specific CO_2 emissions per unit of GDP from China's trading partners, Wang et al., (2007) estimated that a quarter of Chinese CO_2 emissions in 2004 can be attributed to the net exports of goods and services. However, as they admitted this figure might be an over-estimate since they don't distinguish CO_2 emissions intensities for different traded products while a large proportion of Chinese exports have low or medium level of carbon intensity.

To account for pollution emission intensity differences across industries, Dean and Lovely (2008) attempt to source annual Chinese pollution intensities across industries and annual trade data for the years 1995 to 2004. Their results suggest that Chinese exports appear to be much cleaner than Chinese imports. Of the four pollutants (COD, SO_2, smoke and dust) being examined, they found the first three are more intensive in Chinese exports than in imports under the inherent assumption that imports were produced using Chinese technologies. While both exports and imports are becoming cleaner over time, they also found that the difference in pollution intensity in exports and imports are also diminishing.

2.2 I-O techniques

Most studies on this topic have applied input-output techniques which have increasingly become popular in estimating pollution embodiment. Since Leontief's seminal work in 1941, the Input-Output analysis has been employed among studies on various economic issues. It had already been used to analyze the interrelationships between the structures of economy and the factor endowments and comparative advantages before it was introduced into the area of the ecological economics. The following papers discussed apply input-output techniques in some way or another.

Walter (1973) examines the product-profile of U.S. exports and imports and compares it with a pollution profile. Pollution content is defined as environmental control costs consisting of R&D, operating costs, capital cost and appreciation of equipments. For each product group, the direct environmental management cost is estimated and the 1966 U.S. input-output coefficients are applied to account for the indirect costs in intermediate inputs attributable to environmental management. Using 1968-1970 imports and exports data, the author finds that the average annual overall environmental cost loadings in exports as a ratio of exports was insignificant though slightly larger than that of imports using common technology assumption.

Contrary to Walter (1973), most studies investigating pollution content measure the physical flows of emissions such as greenhouse gases (GHG thereafter).

Wyckoff and Roop (1994) argues that many greenhouse gas policies are flawed in the sense that by targeting at domestic emissions they ignore carbon embodied in international trade flows. In order to assess the magnitude of the importation of carbon rich products, they estimate the amount of carbon contained in imports of manufactured goods for six of the largest OECD countries in the mid-1980s: Canada, France, Germany, Japan, the UK and the USA. They use country specific input-output tables, origin specific imports[2], country and industry specific energy use data, and carbon conversion ratio for each fuel type. The authors conclude that the embodiment of carbon in manufactured goods is significant in the mid-1980s with about 13% of the total carbon emissions of the six countries estimated to be embodied in manufactured imports (excluding imports of refined petroleum products).

Antweiler (1996) devised a notion of pollution terms of trade index (PTTI) to eliminate the balance of trade effect in pollution embodiment calculations and assigns weights to different pollutants to get a unique physical dimension. Using the US 1987 IO table, identical technologies assumption (US industrial pollution data) and trade flows, the author calculated the index values for 164 countries in 1987. The results suggest that exports of highly industrialized countries appear to be less

---

[2] It is assumed that imports from any country other than the six OECD countries have been produced using the same technology as the importing country.

environmentally clean than their imports while the opposite holds for the developing countries.

Hayami et al. (1997) investigate the applications of IO techniques in environmental management. The emission of global warming gases in Japan is simulated conditional on the production technology (e.g choice of cement production approaches) and consumer preferences. The authors also compare the SO_2 emission in Japan and China in 1987. Replacing certain characteristics of the Chinese economy by the Japanese counterparts, they find that China could have increased SO_2 emission by adopting Japanese consumption patterns while a substantial reduction would have occurred had Japanese energy usage (patterns, energy efficiency and removal ratio of sulphur and SO_x) installed in the Chinese economy.

As international treaties such as the Kyoto protocol push the issue of global warming into higher platform, a number of researches have been carried out to investigate the question whether producer's responsibility or consumer's responsibility should be accounted for in burden sharing of GHG emissions reduction. For example, Proops et al. (1993) distinguish "CO_2 emission" from "CO_2 responsibility" in comparative input-output study for Germany and the UK. Assuming identical technologies in imports, Munksgaard and Pedersen (2001) use "consumer responsibility" and "producer responsibility" to examine the time series change in Danish CO_2 production and consumption. Using country specific IO tables mostly produced/converted by the OECD Secretariat, Ahmad and Wyckoff (2003) compare "domestic consumption" and "domestic production" in 24 countries (responsible for 80% of global CO_2 emissions) in the mid-1990s.

Increased data availability has enabled related studies focus on the developing countries such as Brazil, Thailand, India and China. Machado et al (2001) use the so-called hybrid input-output model (energy commodities in physical units and non-energy commodities in monetary units) and convert energy data to carbon figures using IPCC 1996 guidelines. They find that in terms of energy and carbon embodiment in trade Brazil is not only a net exporter in non-energy goods but also the embodiment in exports is more substantially intensive than that in imports in 1995.

Using Indian input-output tables for 1991/1992 and 1996/1997 and IPCC guidelines, the two related papers Mukhopadhyay and Chakraborty (2005) and Dietzenbacher and Mukhopadhyay (2007) find that India gained environmentally from international trade in 1991/1992 and 1996/1997. Dietzenbacher and Mukhopadhyay (2007) refer to this phenomenon as Green Leontief Paradox.

Using the same assumptions and IO modelling as in the above two papers, Mukhopadhyay (2006)[3] explores the PHH and FEH for Thailand's trade with OECD countries in the years 1980, 1990 and 2000. It is concluded that Thailand moved from a net pollution importer in earlier years to a net pollution exporter in 2000. It is also implied that the pollution embodied in FDI promoted exports accounts for more than 80% of the total pollution from the export sectors.

Following the same IO modelling and assumptions, Temurshoev (2006) examines the PHH and FEH for the US and China by estimating the air pollutants emitted from fossil fuel combustion. The author concludes from the results that China gains and the US lose in terms of CO_2, SO_2 and NO_x in 1992 and 1997 in terms of pollution emissions in the same amount of extra imports and extra exports). Due to data limitation, the factor endowment embodied in trade was only calculated for the US and it turns out the US is not exporting capital intensive goods similar to the Leontief Paradox.

A "content" version of "pollution haven hypothesis" could be phrased as: developed countries may conduct "environmental dumping" to the countries with laxer environmental regulations by producing and exporting goods that embody less pollution than the imported goods. As result, their consumption contains more pollution than their production. The empirical results are inconclusive and the impression from the selected literature is that a developing country may well be a net importer of pollution content or importer of pollution intensive goods. The existing studies also show that the pollution content in trade changes as the trade volume (scale effect), trade mix (composition effect) and technology of production (technique

[3] Contrary to Copeland and Taylor (2004), the author views the two hypotheses in direct conflict with each other.

effect) change. We aim to investigate whether or not trade liberalisation should be blamed for China's environmental degradation.

3. Methodology and Assumptions

3.1 Pollutants chosen

In this study, we focus on three GHG gases: CO_2, the single largest greenhouse gas in volume as well $SO_2$and NO_x which is directly linked to acid rain and total suspending particulate. It is estimated that the use of solid fuels (coal), liquid fuels (oil) and gaseous fuels (natural gas) contributes to over 90% of CO_2 emissions from fossil fuel combustion[4]. Since these primary energy commodities are built in IO tables, we assume[5] that all the coal, oil and natural gas are combusted whenever they are used as an intermediate input generating greenhouse gases. Combustion process and abatement technologies also affect the final release of GHG emissions. We estimate the emissions generated from combustion process but not the removal of them in abatement process. Combustion process is optimized to derive the maximum amount of energy per unit of fuel consumed, hence delivering the maximum amount of GHG.

3.2 Methodology: the Environmental Input-Output Analysis

The environmental input-output analysis (Leontief, 1970) demonstrates how "externalities" (e.g. pollution) can be incorporated into the conventional input-output picture of an economy. As available input-output tables do not treat pollutants explicitly as "bads" in the input-output matrix, the magnitude of pollution has to be estimated through detailed analysis of the underlying technical relationships and energy dependence.

Compared to measuring the direct pollution emissions in production, the IO formula is advantageous in that it captures the life cycle effect. For example, the life cycle effect of pollution emission in the transport sector not only includes pollution in

4 Emissions can be generated from other sources such as biological metabolism, chemical reactions, and volcanic eruptions, burning wood etc. The magnitude of the emissions generated from these sources may not be negligible. However, they are not explicated analyzed in this study.

5 See also in Mukhopadhyay and Chakraborty (2005), Dietzenbacher and Mukhopadhyay (2007), and Temurshoev (2006).

operation of vehicles but also contains pollution from manufacture and maintenance of vehicles as well as other induced demand. We adopt the environmental IO analysis developed in Miller (1985). This methodology has been used in many studies, for example, Ahmad and Wyckoff (2003), Dietzenbacher and Mukhopadhyay (2007), Mukhopadhyay and Chakraborty (2005), and Temurshoev (2006). It combines the basic concepts of the Input-Output framework and the emission factors suggested by IPCC guidelines[6]. The linear relationships of the interlinked sectors in a Leontief model enable us to investigate the impact of demand (final consumption deliveries) on production and hence on pollution. The model basics are described as follows:

In a particular year **t,** for an individual country **c**, there are **N** commodities each serving as final deliveries as well as intermediate inputs for themselves and other commodities. All the energies are derived from **M** primary energy commodities: Raw Coal, Crude Oil and Natural Gas. Let a_{ij} represent the input coefficient, i.e. the number of units of commodity i needed to produce one unit of commodity j (i, j=1, 2…, N). An N * N matrix of input coefficients is represented by A= {aij}. X is an N * 1 vector denoting domestic output of commodities and Y is an N * 1 vector denoting the final demand. The equilibrium condition of supply equalling demand is captured by the following equation:

$$X=AX+Y; \qquad (1)$$

where Y can be further decomposed into final consumption of domestic goods (Y^D), final consumption of imported goods (Y^M) and goods that are exported (Y^X).

By matrix operational rules, we can solve X as

$$X= (I-A)^{-1}Y \qquad (2)$$

The N * N matrix $\mathbf{(I-A)^{-1}}$ is often referred to as “the Leontief inverse” which represents the totality of the direct and indirect input requirements on domestic goods. This relationship implies that any change in the components of final demand would affect domestic production and in turn any change in domestic production would

[6] IPCC 1996, the manufacture facture of secondary fuels should be ignored in the main calculation, as the carbon in these fuels has already been accounted for in the supply of primary fuels from which they are derived. Refined fuel products are for information only. In the case of fuel combustion, the emissions of non-CO_2 gases contain very small amounts of carbon compared to the CO_2 estimate and, at Tier 1; it is more accurate to base the CO_2 estimate on the total carbon in the fuel. This is because the total carbon in the fuel depends on the fuel alone while the emissions of the non-CO_2 gases depend on many factors such as technologies, maintenance etc which, in general, are not well known. At higher tiers, the amount of carbon in these non-CO_2 gases can be accounted for.

result in the change of pollution emissions and on the environment if we view pollution emissions as “consumption” of domestic environment.

The commodities Coal, Crude oil and Natural gas are the basic fossil fuels. We denote the energy requirement matrix (extracted from matrix A) as **B** of order M * N. Hence b_{ij}[7] refers to the requirement in monetary units on energy commodity i per unit of the output of commodity j.

Chemical emission factors are the product of the net calorific values for each fuel and the chemical (Carbon, Sulfur, Nitrogen) content in net calorific values as suggested in IPCC guidelines. Denote **E** as a 3*M emission matrix for the three GHG emissions per SCE (Standard Coal Equivalent) of combustion for each fuel type.

Since the coefficients in **B** are in monetary units while the coefficients in the emission matrix **E** are in physical units, we have to reconcile the two before multiplication. Comparing the physical units and the monetary units in total fuel output, we could get an approximation for the ratio of SCE/RMB[8] for each energy type in producer’s price. Denote the ratios in M*M diagonal matrix as **R**. Hence the pollution embodied in a final delivery Y (could be output, imports, exports etc) can be calculated using the formula:

$$P = ERB(I - A)^{-1}Y \qquad (3)$$

We also break down the pollution intensity into three elements: direct pollution intensity (DPI), induced pollution intensity (IPI) and overall pollution intensity (OPI) which is the sum of DPI and IPI. Mathematically,

$$DPI=E*R*B*A \qquad (4)$$

$$IPI=E*R*B*[(I-A)^{-1}-A] \qquad (5)$$

$$OPI=E*R*B*(I-A)^{-1} \qquad (6)$$

[7] As Chinese IO tables don’t report imported intermediate inputs separately, this coefficient denotes fuel inputs both domestically produced and imported.

[8] SCE is an acronym of Standard Coal Equivalent which is applied in China and RMB is in current prices.

3.3 Assumptions

Since Chinese IO tables do not distinguish domestic intermediate inputs from imported intermediate inputs, we have to impose alternative assumptions to gauge the estimation and check the robustness. The two alternative assumptions are explained in details in the following two sections.

Assumption 1: intermediate inputs are locally produced only

By assuming no imported intermediate inputs, we adopt matrix A to construct Leontief inverse L. The product matrix of ERB (3*N) denotes emissions in physical units (in tonnes) generated by one monetary unit of output j. The product of the Leontief matrix $(I-A)^{-1}$ and any exogenously defined final demand Y (be it $Y^D, Y^X\, and / or Y^M$ denotes the overall requirement on domestic production).

We use two measures to describe the pollution embodiment in trade: the balance of emissions terms of trade and pollution terms of trade. The balance of emissions terms of trade (BETT thereafter) can be donated as the difference of pollution embodied in exports and pollution embodied in imports:

BETT= $E_c R_c B_c (I-A_c)^{-1} Y^X - \sum_f E_f R_f B_f (I-A_f)^{-1} Y_f^M$ (7)

where c refers to China and f refers to a trading partner that has produced the relevant imports. BETT indicates the net pollution embodiment in China's trade. A positive BETT value suggests that China's exports contain more pollution content than its imports and vice versa. When using identical technologies for Chinese exports and imports, BETT represents the difference between pollution generated from exporting and pollution avoided from importing which can be simplified as:

$ERB(I-A)^{-1}(Y^X - Y^M)$ (8)

Similar to Antweiler (1996) but without assigning weights to pollutants, the pollution term of trade (PTOT) for a pollutant is constructed as the ratio of total pollution intensity in exports and total pollution intensity in imports:

PTOT= $\frac{F^X}{F^M} = \frac{ERB(I-A)^{-1}Y^X / j_I^{'}Y^X}{ERB(I-A)^{-1}Y^M / j_I^{'}Y^M}$ (9)

Where $j^{'}_I$= (1,.., 1) is a 1 by N vector.

PTOT indicates the ratio of the pollution intensity in exports relative to the pollution intensity in imports. If the ratio for a GHG emission is greater than one, the country can be viewed as relatively more pollution intensive in exports than in imports and vice versa.

Assumption 2: import proportionality

Since this study focuses on the impact of trade on pollution emissions by taking into full account of the interdependences of industries, the distinction between domestic produced intermediates and imported intermediates are crucial. Without adjustment, the results based on the technology matrix A will be overestimate (Dietzenbacher et al., 2005; Lahr, 2001).

However, the available technology matrices in the Chinese IO tables don't distinguish the domestic intermediate inputs and the imported intermediate inputs. If the supply-use matrix is applied directly, it is equal to assuming that imports are all final goods. This obviously ignores the role of China in international vertical specialization. When one looks at the fact that China imports of intermediate goods in bulk to process and eventually to export[9], this omission may imply some serious measurement error. For example, it is estimated by Ping et al (2006) that China's vertical specialization ratio rose from 14.2% in 1992 to around 22% in 2003 implying the high volume of China's exports consists of processing trade. Since Chinese IO tables do not give the details of the flows of imported goods[10], we have to make the assumption that imported goods are used as substitutes for domestic goods from which two propositions are generated as follows[11]:

1. Imported goods are proportional in domestic use, be it final deliveries (which includes the possibility of re-exports) or intermediate use;
2. Imported goods are proportional as intermediate use for other sectors.

It is constructed in Chinese IO tables that the sum of gross output and imports equal the sum of intermediate inputs and final demand.

[9] "Processing trade" accounts for almost half of China's total international trade since 1995.
[10] the fallacy of using US-type Input-Output tables, Dietzenbacher et al 2005
11 It is also referred to as Import proportionality assumption which is used by OECD countries to help construct imported goods flow tables. See also Hummels etc (2001), Feenstra and Hanson (1999) and Zhi etl (2002).

Hence, a_{ij} denotes the input requirement of combined (domestic produced and imported) good i to produced one unit of good j. One unit of good i imported is treated as final good as well as substitutive domestic input. Suppose p_i unit of it is used as intermediate goods while 1-p_i unit of it is used as final goods. p_i is calculated as $p_{i.} = \frac{IM_i}{\text{Gross Output}_i + IM_i}$ where IM_i is imports of good i and Gross Output is domestic production of good i. The above two proposition also imply that the ratio of imported input is identical across sectors.

We denote the diagonal matrices of the ratios as follows[12]:

$$\hat{D} = \begin{pmatrix} 1-p_1 & & 0 \\ & \ddots & \\ 0 & & 1-p_n \end{pmatrix}$$

The domestic Leontief inverse matrix becomes $(I - \hat{D}A)^{-1}$. This changes the BETT formula in (8) to:

$$ERB(I-\hat{D}A)^{-1}(Y^X - Y^M) \qquad (8)'$$

And PTOT in (6) becomes:

$$\frac{F^X}{F^M} = \frac{ERB(I-\hat{D}A)^{-1}Y^X / j_I^{'}Y^X}{ERB(I-\hat{D}A)^{-1}Y^M / j_I^{'}Y^M} \qquad (9)'$$

4 Data and Results

4.1 Data

In China, basic IO tables are published both at national and provincial level every five years. Up to now, four basic national IO tables have been published for the years 1987, 1992, 1997 and 2002. Based on the basic IO tables, China also produces extended IO tables every two or three years after a basic one is produced. Available extended IO tables are for the years 1987, 1990, 1992, 1995, 1997, 2000 and 2002. The basic IO tables are more detailed in commodity classifications (over 100 commodities) than

[12] According to convention, a “hat” denotes that the off-diagonal elements are all 0s. By doing so, we calculate commodity specific pollution content in trade

extended IO tables which are aggregated into only dozens of commodities. All the four basic IO tables in China were composed using different commodity classifications highlighting the improved classifications of service sectors. The extended IO tables are less complicated on classifications. The definitions of sectors in extended IO tables are reported in Appendix B.

We use the basic IO tables to calculate the pollution content and pollution intensity embodied in China's trade. The results obtained by employing extended IO tables can serve as sensitivity check of the level of aggregation.

We first assume identical technologies for all the countries or in other words "if imports were made at home".[13] Later we will relax this assumption by using the technologies of a reference country.

Accurate gas emissions from fuel combustion depend on knowledge of several interrelated factors such as fuel types, combustion technology as well as abatement efficiency. Yet, CO_2 emissions are primarily dependent on the carbon content of the fuel which enables calculation at a highly aggregated level (IPCC 1996). However, for SO_2 and NO_x, IPCC guidelines suggest that they are calculated on a detailed activity/technology level. Detailed discussion and calculation of the emission factors can be found in the appendix A. We adopt the following emission factors to construct matrix E.

Table 1 Matrix E: Average Emission Factors (TON/SCE)

	Raw coal	**Crude oil**	**Natural gas**
CO_2	2.712	2.15	1.633
SO_2	0.0225	0.0070	0
NO_x	0.0088	0.0059	0.0044

Note: since crude oil and natural gas are reported together in the 2002 basic IO table and all the extended IO tables, we recalculate the emission factors according to the mix of crude oil and natural gas using annual Chinese energy consumption data.

The above table is consistent with scientific facts in that raw coal is more polluting than crude oil and natural gas. It is also noticeable that carbon dioxide emission factor is much higher that those of sulfur dioxide and nitrous oxides in all the three fuels.

[13] Because of a lack of comprehensive data on technology matrix A, we assume identical technologies across countries, which is common practice in the study on pollution content of trade. See Trefler (1995), Antweiler (1996), Mukhopadyay and Chakraborty (2005).

Usually classified as "no direct local environmental impact" indicator, carbon dioxide has more global impact in nature. Compared to other hazardous local environmental pollutants, governments have fewer incentives to unilaterally address global pollutants due to their widespread impact (Grossman, 1994). Since non-CO_2 gases from fuel combustion are highly technology dependent and we have little information about pollution removal efficiency in each sector, the other two pollutants SO_2 and NO_x will only serve as cross reference and are not involved in further examinations.

Data on energy outputs in monetary units is obtained from Chinese IO tables and energy outputs in physical units are obtained from the Chinese Statistical Yearbooks. We construct the diagonal matrix R as follows:

Table 2 Matrix R (10^{-3} SCE/RMB)

Year	Raw Coal	Crude Oil	Natural Gas
1987	24.27	7.72	10.77
1992	10.98	3.40	15.81
1997	4.40	1.50	2.56
2002	2.59	0.86*	

* In 2002 IO, we only have two primary energy sectors since crude oil and natural gas are reported in a combined manner. We treat producer's prices of crude oil and natural gas as the same.

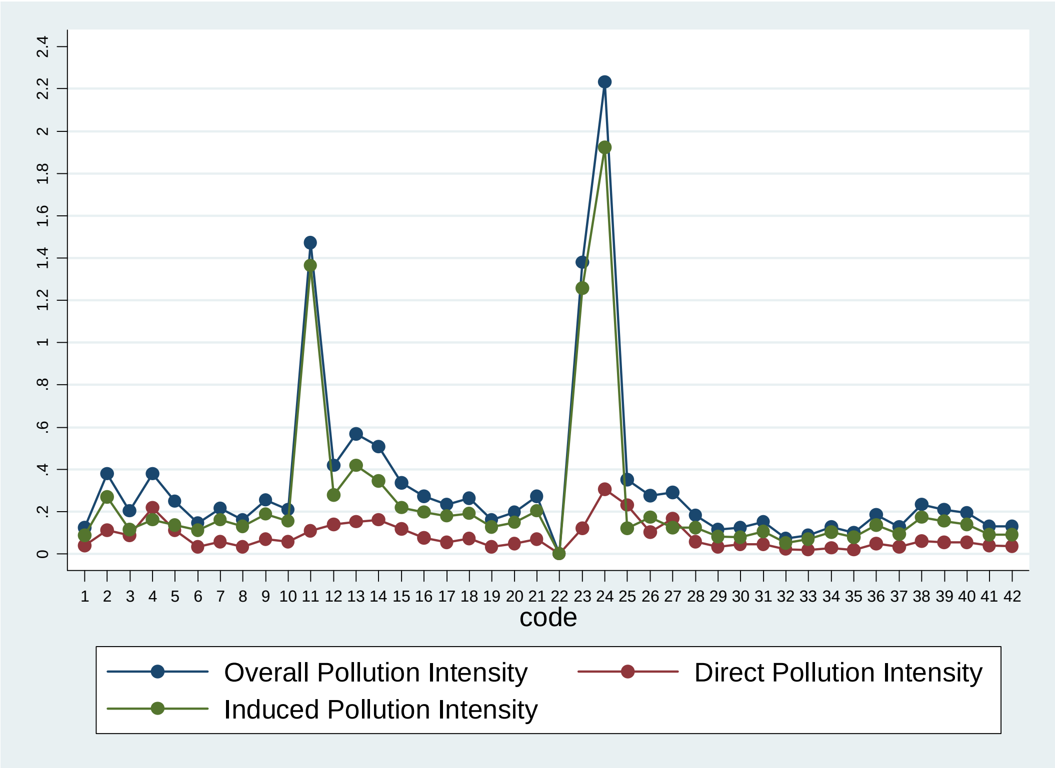
The producer's price of energy differs in fuel type. Crude oil is the most expensive fuel in terms of energy content while raw coal seems to be the cheapest one. The relative prices of fuels have close relationship with the effluence of coal endowments in China. Also we notice that the current prices of fuels have been increasing over the years due to sectoral price level changes.

4.2 Results

4.2.1 Pollution intensity breakdown

We first show the breakdown of pollution intensity at sectoral level. Taking the example of the extended 2002 IO table, the sectoral pollution intensities of carbon dioxide are plotted in diagram 1.

Diagram 1 Sectoral Pollution Intensities of Carbon Dioxide



Note: the intensities are estimated using Assumption 2 of adjusted matrix A; in 10^{-3} tonnes of CO_2 per RMB of sectoral output.

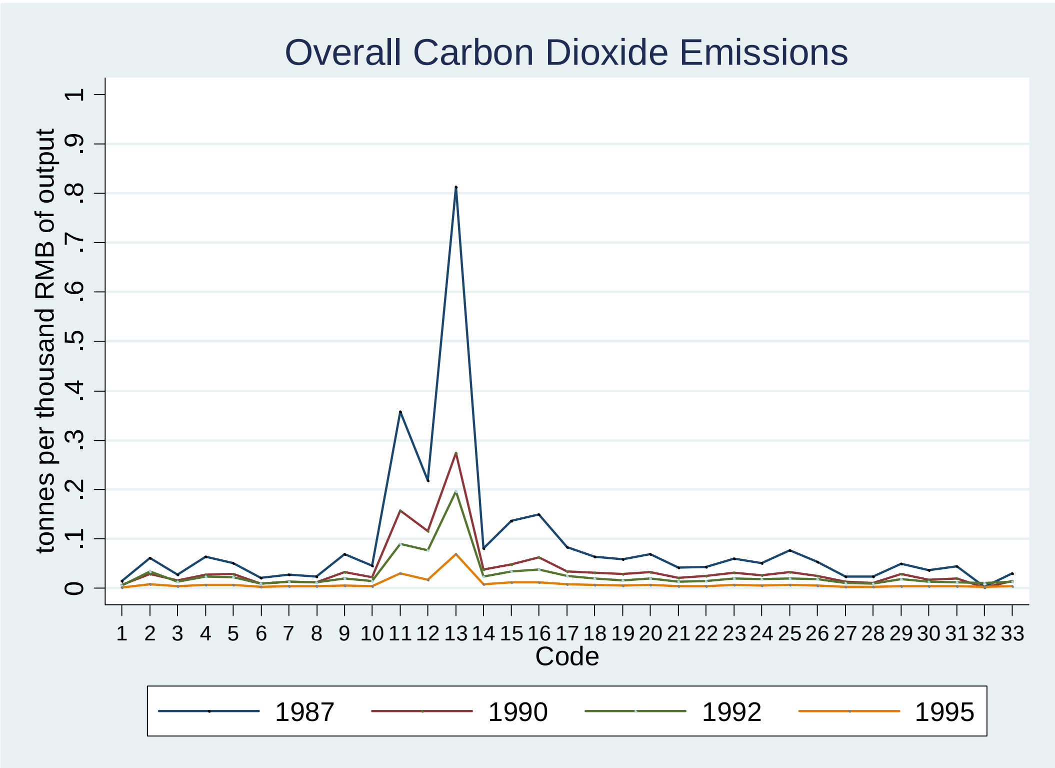
Though the sectoral variations in all the three pollution intensities are quite dramatic, the differences are more prominent in terms of IPI and OPI than DPI. This implies that the impact on the environment from some sectors is more influential than it first appears. Comparing induced pollution intensity with direct pollution intensity, we find that IPI is greater than DPI for most sectors. The only exceptions come from three sectors: 4 Metal mining, 25 Waste and 27 Transportation and warehousing which also have relatively low overall pollution intensities.

We also observe that heavily polluting industries usually have a higher DPI and an enormously huge IPI (for examples, sectors 12 Chemicals, 13 Non-metallic products, 14 Iron and steel, 23 Electricity and steam and 24 Coke and gas products). These sectors not only pollute directly and heavily but also induce huge indirect pollution emitted by its intermediate inputs. This finding contradicts Chung (1998)'s conclusion that major polluting sectors have higher direct pollution intensity than indirect pollution intensity.

Let's take a closer look at sector 24 Coke and gas products: it is the heaviest polluting sector in terms of CO_2 emissions in 2002. However, its direct pollution intensity is only $0.35*10^{-3}$ ton CO_2 per RMB output while indirect pollution intensity is $1.96*10^{-3}$ tonnes CO_2 per RMB output which add up to $2.24*10^{-3}$ tonnes CO_2 per RMB output. The basic conclusions are still held using the basic and other extended IO tables: heavily polluters normally have higher direct pollution intensity and enormously huge indirect pollution intensity.

Since the extended IO tables for 1987, 1990, 1992 and 1995 are constructed using the same IO definitions, we further investigate the evolution of overall pollution intensity of CO_2 at sectoral level.

Diagram 2 Evolution of CO_2 Intensity



Note: To enable compatibility, all prices are inflated to 2002 level; price indices are from China statistical yearbooks; 10^{-3} tonnes of CO_2 per RMB of output;

It shows that over the years the emission intensities have been decreasing for almost all the sectors and the most dramatic changes come from the heavily polluting sectors: 11 Petroleum refineries, 12 Chemicals, 13 Non-metal mineral products, 15 Metal products, and 16 Machinery. The most noticeable decrease in overall pollution intensity lies in 13 Non-metal mineral products (including cement, stone and clay products which are in many studies listed as notorious heavy polluters); the overall pollution intensity of this sector decreased from over 0.8 tonnes CO_2 per RMB of output to 0.27 tonnes CO_2 per RMB of output.

4.2.2 Basic results

We report the basic results for pollution generated from exporting and pollution avoided from importing using existing Chinese IO tables. Trade data are from the Chinese IO tables. The results based on the basic IO tables and assumption one are reported in table 3.

Table 3 BETT and PTOT using Assumption one

Year	**Pollutant**	**BETT** 10^4 **tonnes**	**PTOT**
1987	CO_2	-18276	-
	SO_2	-140	-
	NO_x	-58	-
1992	CO_2	-11138	<1
	SO_2	-73	<1
	NO_x	-34	<1
1997	CO_2	877	0.78
	SO_2	28	0.81
	NO_x	4	0.79
2002	CO_2	-11698	0.74
	SO_2	-79	0.74
	NO_x	-36	0.77

Note: In 1987 and 1992 IO tables, only net exports are reported. In 1987, China has trade deficit equalling to 4343416 (10^4 RMB) and in 1992 net exports is 2507565 (10^4 RMB). .

Assuming common Chinese technologies to produce exports and imports, it seems that China does not fit in the term "pollution haven" well. The table above shows that the China's pollution content in net exports turns out to be negative for the three air pollutants in the years except 1997. This absolute measure suggests that in most of the years investigated China has "pollution deficit" relative to the rest of the world from international trade. The implication is surprising given that China has an enormous trade surplus since 1990s. The PTOT index shows that in terms of any of the three pollutants China's imports are more pollution intensive than its exports in 1992[14], 1997 and 2002. Also the results suggest that China's exports are becoming slightly less pollution intensive from 1997 to 2002, which may be caused by advancement in production technologies and changes in trade mix.

Now we turn to the results obtained from the adjusted domestic technology matrix. The results are reported in table 4.

Table 4   BETT and PTOT using Assumption 2

Year	Pollutant	BETT 10^4 tonnes	PTOT
1997	CO_2	-1250	0.76
	SO_2	-14	0.79
	NO_2	-2	0.77
2002	CO_2	-12903	0.74
	SO_2	-86	0.74
	NO_2	-39	0.74

Since the IO tables of 1987 and 1992 don't report imports and exports of commodities separately, our simple proportionality approach could only apply to the 1997 and 2002 IO tables. The values of pollution content in both exports and imports are now smaller than those obtained without "proportionality" .The BETT values in the table above shows that as a country with enormous trade surplus China runs a "pollution deficit" in both 1997 and 2002. After excluding the pollution embodied in imported intermediate inputs, the BETT values for 1997 change from positive in the previous estimation to negative in the table above, which may indicate the importance of processing trade in some polluting industries in China as well as measurement error due to the simple approach of "import proportionality" .

With smaller magnitudes than before, the PTOT values still suggest China's imports are more pollution intensive than its exports. And China's exports are becoming slightly less pollution intensive from 1997 to 2002. The results lead to a bold

[14] It is inferred from the data that the PTOT index for China in 1992 is less than 1.

implication that China has relatively less competitive advantage in “dirty” industries than in “clean” industries.

We also use the more aggregated extended IO tables to carry out sensitivity check. There are 33 sectors for the 1987,1990,1992,1995 extended IO tables, 40 sectors for 1997, 17 sectors for 2000 and 42 sectors for 2002. Same methodologies and assumptions are applied to obtain BETT and PTOT values.

Table 5 BEET in 10^4 tonnes (Sensitivity Check)

Year	Assumption	Sectors	CO_2	SO_2	NO_x
1987	1	33	-15511.1	-125.2	-50
1990	1	33	-879.3	-15.7	-3.6
1992	1	33	-5903.7	-40.7	-18.4
1995	1	33	-2768.7	-9.9	-7.7
1997	1	40	3801.1	41.0	13.2
1997	2	40	2181.7	30.0	8.2
2002	1	42	-2365.6	-9.8	-6.7
2002	2	42	-2652.3	-11.3	-7.6

The conclusions from our previous analysis hold in the sensitivity check for most of the years, i.e, China runs a “pollution deficit” in most of the years except 1997. It is also shown that even under the “import proportionality” approach; we find that China has more pollution embodiment in exports than that in imports in 1997. This doesn’t coincide with the earlier results from using the basic 1997 IO table. It seems that aggregation level would affect the results. Should we use a more disaggregated IO table, the results for BEET may change too.

The following table presents the PTOT values. Though larger than the previous results, the PTOT values consistently suggest China’s imports are more pollution intensive than its exports. However, contrary to the previous estimation based on the basic IO tables, the values are getting bigger from 1997 to 2002. It seems that to some extent aggregation level also matters to PTOT values. Extra care should be taken towards our earlier conclusion on whether China is moving further away from “pollution haven”

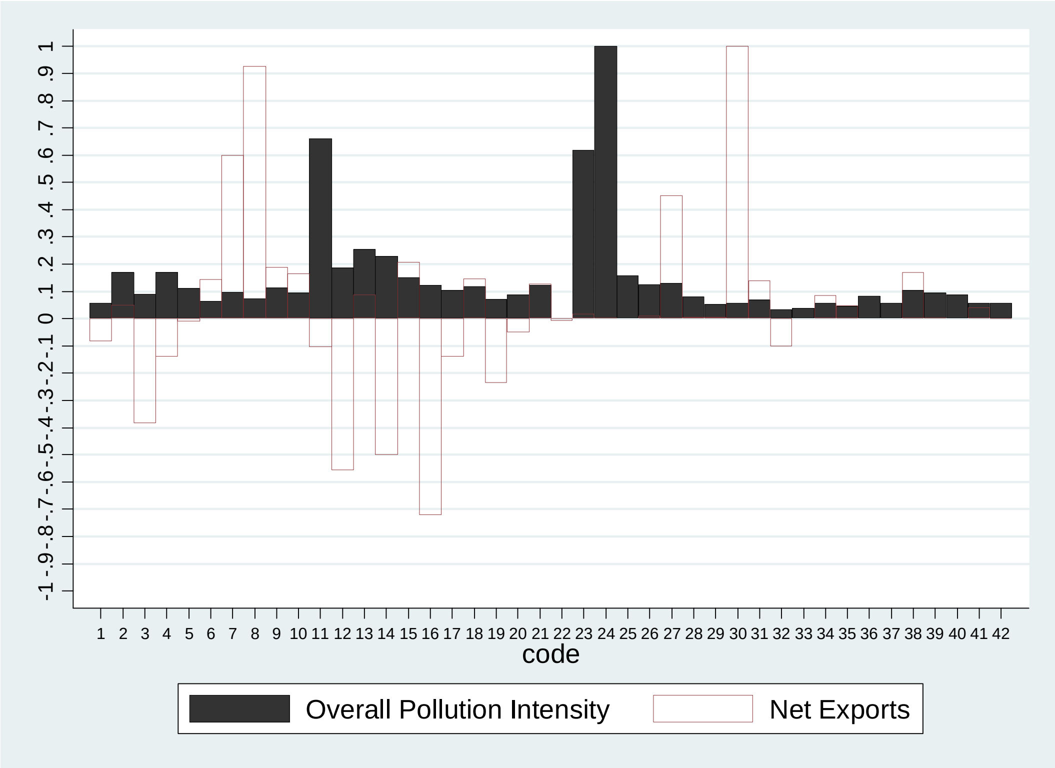
Table 6 PTOT from Extended IO tables (Robustness Check)

Year	**Sectors**	**CO_2**	**SO_2**	**NO_x**
1997	40	0.81	0.83	0.81
1997 domesticated	40	0.80	0.82	0.80
2002	42	0.85	0.86	0.85
2002 domesticated	42	0.84	0.85	0.84

Based on the main results and the sensitivity check, we conclude that China's imports more pollution embodiment than its exports in most of the years except in 1997 when there is ambiguity under different aggregation levels. Besides, China's exports are less pollution intensive than its imports. In other words, China's environment would get worse for it to stop exporting and produce the imports domestically.

The fact that China's exports are greener than its imports has its root in sectoral trade patterns. To visualize the relationship between net exports and overall pollution intensity, normalisation is carried out for the two variables. The sector with the largest net exports value (30 wholesale and retail) is taken as 1 whilst the net exports of the other sectors are expressed as its ratio. Similarly the overall pollution intensity of the most polluting sector (24 Coking) is taken as 1.

Diagram 3 Visualisation of Pollution Intensity and Net Exports

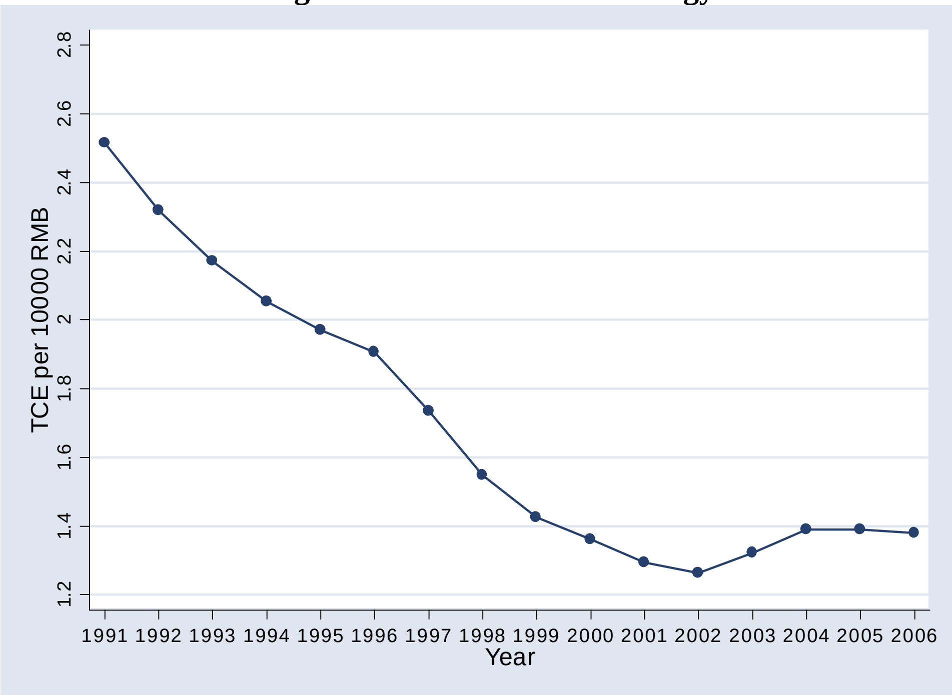


The diagram shows that China has large trade surplus in the relatively clean sectors such as (7 Textiles, 8 Wearing apparel, 27 Transportation and warehouse, 30 Wholesale and retail). In the dirty sectors, China either has a tiny trade surplus (e.g. the sectors 13 Non-metal mineral products, 23 Electricity and heat and 24 Gas) or runs a trade deficit (sectors 11 Petroleum refineries, 12 Chemicals and 14 Metal smelting). These findings validate our earlier conclusions of BETT and PTOT. It seems to suggest that China has competitive advantage in clean industries.

4.2.3 Projection for recent years

Next question we ask is whether trade liberalisation accompanying China's accession into WTO has changed the situation of pollution embodiment in China's trade. Since the basic 2002 IO table is the latest table available for Chinese economy, we have to adopt the 2002 IO table for projection. The crucial assumptions in using the same IO table to project pollution embodiment for later years are that the technology in use and relative prices (IO tables normally report coefficients in monetary units) remain constant over time. For a short period of time, these assumptions are not unreasonable. But as a developing country, it is believed that the production techniques/process over the last decade has improved efficiency. To examine the overall energy efficiency, we plot the energy consumption per unit of output in the following diagram.

Diagram 4 Evolution of Energy Intensities



Source: China Energy Yearbooks various editions; in 2002 constant price.

The energy requirement for per unit GDP output in China has experienced dramatic decreases in the last decade which may attribute to a number of factors including both efficiency increase and structural adjustment. (See Garbaccio et al, 1999; Sinton and Fridley, 2000) However, this trend comes to a halt in 2002; the energy intensity in recent years has been higher than the lowest point in 2002 and remains rather stable since 2004.

However, we don't have information on sectoral energy information as well as relative prices. To compromise, we restrict the analysis to the composition effect (trade mix) only. Other things equal, will China's deepened trade with the rest of the world reverse the trend and turn China into a pollution haven (we define as PTOT>1)? We examine whether the composition effect could have played an important role in later years given the 2002 production technologies.

Trade data is in HS 2002 code and obtained from UNCOMTRADE database. It is then converted to Chinese IO 2002 code. The database only report data of commodity trade which can be grouped into 85 sectors (see attachment of the 85 sectors). We hence forgo the service trade in the projection. These import values are on a CIF basis while export values are on FOB basis. No adjustment such as customs duties is applied.

Table 7 Pollution Embodiment in Commodity Trade

Year	Pollutant	BETT 10^4 tonnes	PTOT
	CO2	-12760	0.78
2002	SO2	-75	0.79
	NO2	-39	0.78
	CO2	-22625	0.76
2003	SO2	-143	0.78
	NO2	-69	0.77
	CO2	-27514	0.78
2004	SO2	-160	0.81
	NO2	-83	0.79
	CO2	-18089	0.79
2005	SO2	-98	0.81
	NO2	-54	0.79
	CO2	-9620	0.80
2006	SO2	-19	0.83
	NO2	-24	0.80

Both measures are consistent with earlier conclusions. BETT values are all negative regardless of the years and pollutants. It also shows that the net avoided pollution in commodities at first increased and then decreased for all the three pollutants. It is noticed that the PTOT values also experienced some variation across the years but still remain less than 1 regardless of the years and pollutants we examined. It seems that the composition effect alone does not change the trend that Chinese exports are greener than its imports.

With ups and downs in between, the export pollution intensity is roughly the same in 2002 and 2006. In the meanwhile, the imports pollution intensity has slightly decreased. See the illustration diagram B6 in the appendix B.

To sum up, our analysis based on common technology assumption shows that for the years we studied the volume of air pollution avoided by importing is larger than that of emitted by exporting. Also, it seems that China gains environmentally in the sense that Chinese exports are relatively less pollution intensive than imports.

4.2.4 Heterogeous technologies

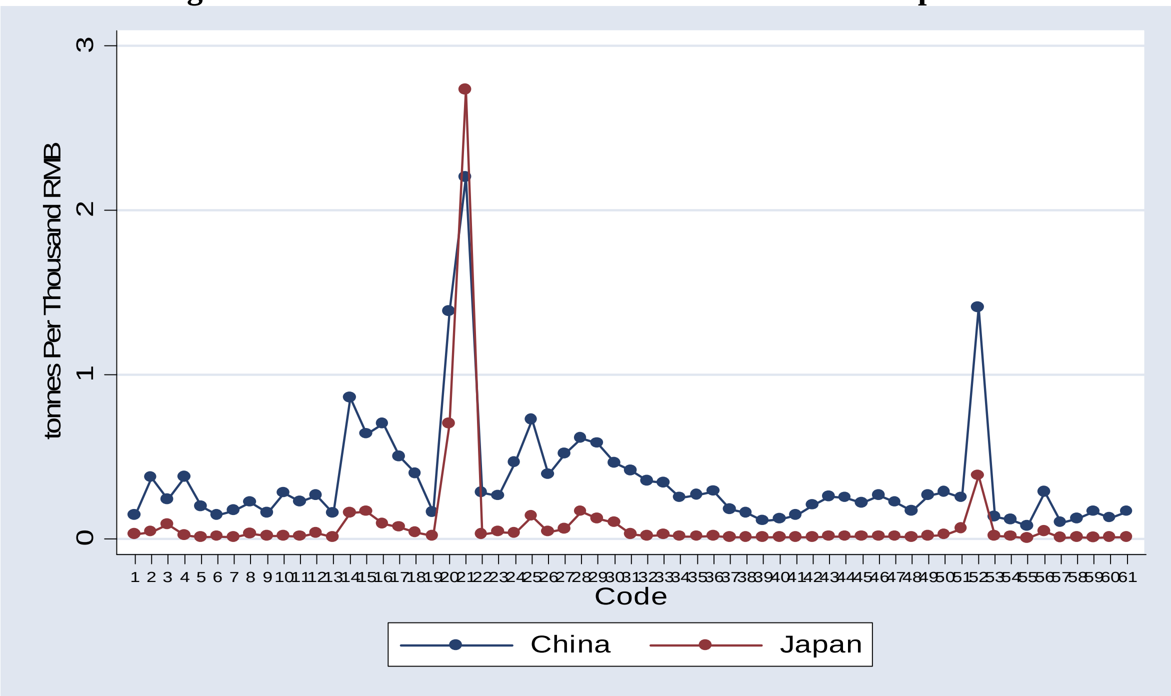
So far our calculations have been based on the implicit assumption that countries share the same production technologies. For a developing country that trades a lot with developed countries this assumption implies that there is an overestimate in pollution embodied in imports. Firstly, countries differ in their energy structure and energy efficiency. For example, China has a coal predominated energy structure which depends heavily on fossil fuels while its trading partners especially OECD countries depend more on cleaner fuels partly due to pollution limits constrained by international agreements and national regulations. The sectors also have different inter-dependences across countries expressed in the differences in input output matrices. A better way to tackle these issues is by distinguishing source origins of the trade and applying country specific Input-Output tables. We use Japan[15] as a reference country based on the facts that Japan is one of the most important trading partners to China and also Japan adopts a similar structure of commodity by commodity IO tables as China. To make the IO tables comparable, we need to aggregate the sectors. We use the 71-commodity Japanese extended IO table and the 122-commodity bench mark Chinese IO table for the year 2002. Then we aggregate the commodities into 61 sectors. (1997 Japanese extended IO tables only have 41 sectors which does not distinguish coal from oil and natural gas.) Trade data is derived from Chinese 2002 IO table.

As before, we plot the overall pollution intensities for China and Japan in 2002 in terms of carbon dioxide emissions. The diagram shows that Japan has an overall advantage in energy efficiency. The only one exception is sector 21 Coking which is

[15] Japan has since 1955 been producing extensive bench-mark IO tables every five years and producing extended IO tables annually. The Japanese Statistics Bureau website provides the 1995 basic IO tables (93 sectors) and the 2000 basic IO tables (104) sectors. From the website of Japanese Ministry of Economy Trade and Industry, I found IO tables for various years based on the basic IO tables. There are IO tables (71 or 50 sectors) for the years 1997 to 2002 based on the bench mark 1995 IO tables and IO tables (186, 73 or 50 sectors) for the years 2003 to 2006 based on the bench mark 2000.

the heaviest polluting industry in both economies. Japan has less sectoral variation in pollution intensity compared to China. There are several sectors which significantly lag behind their Japanese counterparts. For example, the second heaviest polluting sector in both economies is 52 Electricity, steam and hot water production; however China's pollution intensity of sector 52 is about 3.6 times of that in Japan.

Diagram 5 Overall Pollution Intensities in China and Japan



Using the methodologies and data outlined in the previous sections, we calculate and report the pollution content of China's international trade in 2002. The results are divided in three groups as shown in the following table.

Table 8 Pollution Content Based on Alternative Technologies

IO tables	Pollutants	BETT (10^4 tones)	PTOT
1) Common Tech	CO_2	-12533	0.98
Exports using CN[a]	SO_2	-80	0.99
Imports using CN	NO_x	-38	0.98
2) Heterogenous Tech	CO_2	23998	1.74
Exports using CN	SO_2	183	1.84
Imports using JP[b]	NO_x	76	1.76
3) Common Tech	CO_2	-11300	0.87
Exports using JP	SO_2	-76	0.86
Imports using JP	NO_x	-35	0.87

a. Represents the 61 sector Chinese IO table. b. Represents the 61 sector Japanese IO table.

The first set of results replicates the calculations of pollution content based on common Chinese technologies for exports and imports using the newly aggregated 61 sector Chinese IO table. The same conclusions can be drawn as we already knew from previous analysis; BETT shows a net “environmental gain” in terms of the three air pollutants from fossil fuel combustion; PTOT indicates Chinese exports are relatively cleaner than its imports. Yet the conclusions from PTOT indices are weakened by the fact that pollution intensity in exports is very close to that of imports. This again shows that aggregation plays a role in the magnitude of these indices.

The second set of results is based on heterogeous technologies represented by the Japanese IO tables. Pollution content in exports is calculated by using Chinese IO table while pollution content in imports is calculated by using Japanese IO table. We reach the reversed results that China actually exported more pollution content than imported and its exports pollution intensity is almost twice of its imports pollution intensity. It implies that the globe as a whole could have to accommodate more air pollution because of this trade liberalization. Of course, the validity of Japan as a reference country and the results are open to robustness check.

The simulation results are reported lastly based on the assumption that China’s exports were produced using Japanese energy structure and technologies. Compared to the first set of results, we see little change in net exports of pollution content and China would be a net importer of pollution content. With smaller PTOT values than those in the first set of results, China’s exports would still be cleaner than its imports. The difference of PTOT values in the first and third sets of results can be viewed as the technique effect that would generate from technological advances.

5 Conclusions

This paper extends the previous studies on pollution content of trade in China in a number of ways. Firstly, we use up-to-date Chinese IO tables which are most comprehensive in details compared to those used in other studies. This extensiveness also enables sensitivity check on aggregation bias. Secondly we also break down pollution intensity into three elements based on the directness of pollution generation. Our results have both consistence and contradiction to Chung (1998)’s findings.

Thirdly, based on the 2002 IO table, we explore the composition effect of international trade on the environment since China’s accession into WTO in 2001. Last but not least, we simulate the pollution content in trade using alternative technology assumption using Japan as a reference country of China’s trading partners.

Quite different from the conventional wisdom, our study shows that China “avoids” more air pollution by imports than “puts in” by exports and its exports are cleaner than imports under common technology assumption. Time-series breakdown also shows that Chinese sectoral pollution intensities have been decreasing over the years. Controlling the technology matrix in 2002, we find that the composition effect contributes positively to China’s environment and it alone overcomes scale effect and benefits China’s environment in terms of balances of emission terms of trade.

However, the good news for China may not be the good news for the globe as we have shown that air pollution would have been less were the Chinese exports produced in a developed country (such as Japan). There are several sectors (for example, Electricity production, Petroleum refineries and Chemical fertilizers) in China which have much higher overall pollution intensities than their Japanese counterparts and most likely higher than many of other OECD countries. The simulation results imply that China’s progress in technologies will mean significantly for the control of global environmental issues.

Our findings are very much consistent with many other studies as shown in the table B3 in Appendix B. However, we are also aware that our study has several caveats which need to be addressed in further research work. The first shortcoming stems from our adjustment method of imported intermediate inputs. The “import proportionality” assumption may be oversimplified and the results without any robustness check need to be dealt with caution. Also most of the pollution contents are calculated based on Chinese IO tables. Whilst such calculations show China’s trade off in terms of pollution content, they by no means exactly reflect the impact of trade liberalisation on the environment of the globe as whole. Although we have employed Japanese IO tables to elaborate, the results are open to be scrutinized.

Reference

1. Andrew W. Wyckoff and Joseph M.Roop. 1994. The Embodiment of Carbon in Imports of Manufactured Products. (Implications for International agreements on greenhouse gas emissions). Butterworth-Heinemann Ltd
2. Arik Levinson, 2007. Globalization and Pollution from US manufacturing.
3. Erik Dietzenbacher, Vito Albiono and Silvana Kühtz, 2005. The Fallacy of Using US-Type Input-Output Tables.
4. Erik Dietzenbacher and Kakali Mukhopadhyay, 2007. An Empirical Examination of the Pollution Haven Hypothesis for India: Towards a Green Leontief Paradox?
5. Giovani Machado, Roberto Schaeffer, Ernst Worrell. 2001. Energy and Carbon Embodied in the International Trade of Brazil: an Input-Output Approach. Ecological Economics 39 (2001) 409-424
6. Hitoshi Hayami, Masao Nakamura, Mikio Suga and Kanji Yoshioka, 1997. Environmental Management in Japan: Applications of Input-Output Analysis to the Emission of Global Warming Gases. Managerial and Decision Economics, VOL. 18, 195-208.
7. Hyun-Sik Chung, 1998. Why Do CO_2 Emissions Differ in China, Japan and Korea? Oxford Institute for Energy Studies. EV25
8. Ingo Walter, *1973, The Pollution Content of American Trade, Economic Inquiry, Vol. 11 Issue 1 page 61-70.*
9. Jean-Marie Grether, Nicole Mathys, Jaime de Melo. 2005. A Gravity Analysis of the Pollution Content of Trade （work in progress）
10. Judith M. Dean and Mary.E. Lovely. Trade Growth, Production Fragmentation, and China’s Environment. 2008 NBER Working Paper No. 13860
11. Jean-Marie Grether, Nicole A. Mathys and Jaime de Melo, 2006. Unraveling the World Pollution Haven Effect World Bank Policy Research Working Paper 4047, November 2006
12. Joel Bruneau and Cristina Echevarria ,2003, Environmental quality is a normal good.
13. Kakali Mukhopadhyay. 2006 Impact on the Environment of Thailand’s Trade with OECD countries. Asia-Pacific Trade and Investment Review. Vol.2, No.1,
14. Kakali Mukhopadhyay and Debesh Chakraborty, 2005. Environmental Impacts of Trade in India, The International Trade Journal, Vol. XIX. No. 2 p 135-163.
15. Manfred Lenzen, 2001. A Generalized Input-Output Multiplier Calculus for Australia. Economic Systems Research, Vol. 13, No.1, 2001.
16. Miller, R.E. Input-Output Analysis. 1985. Prentice Hall.
17. Ping 2006, vertical specialization in china’s exports and Sino-US trade
18. Roldan Muradian, Martin O´Connor, Joan Martinez-Alier. 2001. Embodies Pollution in Trade: Estimating the ‘Environmental Load Displacement’ of Industrialized Countries. Cahier du C3ED n˚01-02
19. Temurshoev, Umed. 2006. Pollution Haven Hypothesis or Factor Endowment Hypothesis: Theory and Empirical Examination for the US and China. Working Paper Series ISSN 1211-3298
20. Wassily Leontief, 1953. Domestic Production and Foreign Trade; the American Capital Position Re-Examined. Proceedings of the American Philosophical Society, Vol.97, No.4.pp.332-349.

21. Wassily Leontief, 1958. Factor Proportions and the Structure of American Trade: Further Theoretical and Empirical Analysis: Reply. The Review of Economics and Statistics, Vol.40, No.1, Part 2. Problems in International Economics. Feb.,1958, pp. 119-122
22. Wassily Leontief, 1970. Environmental repercussions and the Economic structure: an input-output approach. Review of Economics Statistics 52 (3), 262-271.
23. Werner Antweiler, 1996, the Pollution Terms of Trade. Economic Systems Research, Vol.8, No.4, 1996.

Appendix A

Construction of Emission Factors

1. Emission factors used in other studies

In this study of air pollutants from fossil fuel combustion, we are concerned with the content of carbon, sulfur and nitrogen in fuels. However, there are many types of coal, oil and natural gas which vary dramatically in their chemical contents in physical units. Less variation is found in terms of emission in calorific terms. That is why most energy resources give out emissions factors in calorific terms rather than emission factors in physical terms. Because of this complexion, some emission factors are misused in some studies. The following is a comparison of average emission factors in four related studies:

Table A1 Comparison of Emission factors

Author	Units	Carbon in			Sulfur in			Nitrogen in		
		Coal	Oil	Natural Gas	Coal	Oil	Natural Gas	Coal	Oil	Natural Gas
Mukhodpadhyay (2002)	mt/mt[a]	0.55	0.77	0.67	n/a[c]	n/a	n/a	n/a	n/a	n/a
Mukhopadhyay and Chakroborty (2005)	mt/mt	0.55	0.79	n/a	0.003	0.015	n/a	0.018	0.001	n/a
Dietzenbacher and Mukhopadhyay (2007)	mt/mtoe[b]	0.55	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Temurshoev (2006)	mt/mtoe	0.55	0.77	n/a	0.003	0.015	n/a	0.018	0.001	n/a

Note: a. mt/mt is acronym for million tonnes per million tonnes;

b. mt/mtoe is acronym for million tonnes per million tonnes oil equivalent;

c. not explicitly mentioned in the text. However the emission factors of oil and natural gas usually adopt the same values.

While we find the numbers used in these studies are almost the same, the units they are using are surprisingly different: mtoe is a measure of energy and mt is a measure of physical mass. In the case of coal, 2 mt of coal would release about 1 mtoe of energy. Hence, the emission factors in some, if not all, of the studies, are misused.

2. Emission factors used in this study

CO_2 emissions are primarily dependent on the carbon content of the fuel and hence we can calculate them from fuel combustion accurately at a highly aggregated level. But for SO_2 and NO_x, emissions estimation requires more detailed information. Accurate estimation of their emissions depends on knowledge of several interrelated factors, including combustion conditions, technology, and emission control policies, as well as fuel characteristics. IPCC guidelines suggest that they are calculated based on applied on a detailed activity/technology level.

Emission factors vary in fuel types as well as across industries and from different data sources. Peter et, al (2006) compare emission factors from Chinese Energy Statistics Yearbooks, CCCS and IPCC guidelines as well as other studies. We use these sources to construct emission factors for the three air pollutants.

2.1 Carbon Dioxide Emissions

According to IPCC guidelines, we can construct carbon dioxide emission factors by multiplying the carbon emission factor of the corresponding fuel by the fraction of carbon oxidized and the molecular weight ratio of carbon dioxide to carbon. There is certain yet small variation in the carbon emission factors reported by different sources. The following table presents a selection of emission factors from IPCC EFDB.

Table A2 Carbon Emission factor and Fraction of Carbon Oxidized

Fuel Type	**Coal**	Soft coke	**Natural gas**	LPG	Naphtha	Motor gasoline	**Fuel oil**
Emission factors (T C/TJ)	**25.8**	25.8	**15.3**	17.2	20.0	18.9	**20.2**
Oxidization factors[a]	**0.98**	0.98	**0.995**	0.995	0.99	0.99	**0.99**

Source: IPCC guidelines. a. Oxidization factor vary across industries ranging from 0.8 to 0.98. We use the default values which are overestimates for some industry.

We use the values in bold to construct our carbon dioxide emission factors. To make the values comparable to other studies and to suit the Chinese case, we also present the carbon emission factors in different units.

Table A3 Carbon emission factors in different units

Fuel type	T C/TJ	T C/SCE[a]	T C/TOE[b]	T C/ T[c]
Raw Coal	25.8	0.75613608	1.0801944	0.5394264
Crude Oil	20.2	0.59201352	0.8457336	0.8446832
Natural gas	15.3	0.44840628	0.6405804	n/a

Note: a. SCE is an acronym of Standard Coal Equivalent which refers to the amount of energy released by burning one metric ton of coal. It is widely used in Chinese energy statistics.1 SCE=29.3076*10^{-3}TJ

b. TOE is an acronym of Ton Oil Equivalent which refers to the amount of energy released by burning one metric ton of oil. It is accepted by many nations to record their energy statistics. 1 TOE=41.868*10^{-3} TJ. 1 SCE is about 0.7 TOE.

c. T denotes one metric ton. We use net calorific values for raw coal 0.020908 TJ per ton and for crude oil 0.041816 TJ. per ton. Natural gas is often measured in volume and thereby we don't report the carbon content in physical mass.

3.66 is applied as the molecular weight ratio of carbon dioxide to carbon. The following is carbon dioxide emission factors based on the methodology and data mentioned above.

Table A4 Carbon Dioxide Emission factors

Fuel type	Raw Coal	Crude Oil	Natural Gas
CO_2 ton per SCE	2.712	2.145	1.633
CO_2 ton per TOE	3.874	3.064	2.333

2.2 Sulfur Dioxide Emission Factors

Sulfur dioxide emission factors are constructed by multiplying the sulfur content of the corresponding fuel by the fraction of sulfur oxidized and the molecular weight ratio of sulfur dioxide to sulfur.

Table A5 Sulfur Content in Different Fuels (%)

Fuel type	Raw Coal	Crude Oil	Natural Gas
IPCC low	0.5	1	n/a
IPCC medium	**1.5**	**3**	**0**
IPCC high	3	4	n/a
Jingru	1.1	0.5	n/a

Source: Peters et al (2006)

Not all the sulfur content in fuels will be oxidized; there will be certain proportion of remains in ash. Sulfur content and retention in ash varies dramatically in fuel types.

IPCC provides various values of sulfur content and retention in ash according to fuel types. The table below shows a variation in estimation in different data sources.

Table A6 Sulfur Retention in Ash (%)

Fuel type	Raw Coal	Crude Oil	Natural Gas
IPCC, hard coal	5	n/a	n/a
IPCC, brown coal	30	n/a	n/a
Jingru	20	n/a	n/a
CCCS, P53	**27**	**n/a**	**n/a**

Source: peters et al 2006

We use IPCC medium sulfur content values (in bold) and sulfur retention ratio in ash 27% according to CCCCS. Due to data limitation, we imply a strong assumption that sulfur removal technology is absent/ inefficient.

We use 2 as the molecular weight ratio of sulfur dioxide to sulfur.

Table A7 Sulfur Dioxide Emission Factors using jingru sulfur content

Fuel	t /SCE	t /TOE	t/ T	KT/PJ
Raw coal	**0.0225**	0.0322	0.0161	0.768127
Crude oil	**0.0070**	0.0100	0.0100	0.2391429
Natural gas	**0**	0	n/a	0

Source: peters et al (2006)

2.3 Nitrous Oxides Emission Factors

Similar to SO_2, nitrous oxides from fuel combustion are highly technology dependent. Nevertheless, we use IPCC default nitrous oxides emission factors numbers for industry/energy and construction as follows.

Table A8 Nitrous Oxides Emission Factors

Fuel	t /SCE	t/TOE	t/T	kg/TJ
Raw Coal	**0.00879228**	0.0125604	0.0062724	300
Crude Oil	**0.00586152**	0.0083736	0.0083632	200
Natural gas	**0.00439614**	0.0062802	n/a	150

Note: Nitrogen emission factors are IPCC default numbers for the sectors Industry, Energy and Construction.

3. Summary

To sum up, we use emission factors as the following table listed

Table A9 Emission factors ton/SCE

	CO_2	SO_2	NO_X
Raw coal	2.712	0.0225	0.0088
Crude oil	2.145	0.0070	0.0059
Natural gas	1.633	0	0.0044

For 2002, where crude oil and natural gas are referred to in the IO tables as one commodity, we recalculate the emission factors based on the mix of crude oil and natural gas in Chinese energy production/consumption.

Appendix B

Table B1 Definitions of Codes in Different Extended IO Tables

Codes	1987/1990/1992/1995	1997	2002
1	Agriculture	Agriculture	Agriculture
2	Coal mining and washing	Coal mining and washing	Coal mining and washing
3	Crude petroleum and natural gas	Crude petroleum and natural gas	Crude petroleum and natural gas
4	Metal mining	Metal mining	Metal mining
5	Other mining	Other mining	Other mining
6	Food and tobacco	Food and tobacco	Food and tobacco
7	Textiles	Textiles	Textiles
8	Wearing apparel	Wearing apparel	Wearing apparel
9	Wood and furniture	Wood and furniture	Wood and furniture
0	Paper and educational products	Paper and educational products	Paper and educational products
11	Electricity, steam and hot water	Petroleum	Petroleum
12	Petroleum	Chemicals	Chemicals
13	Gas and coke products	Non-metallic products	Non-metallic products
14	Chemicals	Iron and steel	Iron and steel
15	Non-metallic products	Metal products	Metal products
16	Iron and steel	Machinery, non-electric	Machinery, non-electric
17	Metal products	Transport equipment	Transport equipment
18	Machinery, non-eletric	Machinery, eletric	Machinery, eletric
19	Transport equipment	Electronic and communication appratus	Electronic and communication appratus
20	Machinery, eletric	Professional and scientific equipment	Professional and scientific equipment
21	Electronic and communication appratus	Machinery repair	Other manufacturing
22	Professional and scientific equipment	Other manufacturing	Waste
23	Machinery repair	Waste	Electricity and steam
24	Other manufacturing	Electricity and steam	Gas
25	Construction	Gas	Waster
26	Transportation and postal services	Waster	Construction
27	Business	Construction	Transportation and warehouse
28	Restaurant	Transportation and warehouse	Postal services

29	Passenger transportation	Postal services	Information and software
30	Public and residential services	Business	Whole sale and retail
31	Cultural, Educational, sports and scientific research	Restaurant	Hotel and restaurant
32	Finance and insurance	Passenger transportation	Finance and insurance
33	Administration	Finance and insurance	Real estate
34		Real estate	Renting and business services
35		Social services	Travel
36		Health, sports and social welfare	Scientific research
37		Education, arts,cultural and recreational services	General technical services
38		Scientific research	Other social services
39		General technical services	Education
40		Public administration	Health and social welfare
41			Cultrual, sports and recreational
42			Public administration and public organizations

Table B2 61 sectors for China and Japan in 2002

Code	Description
1	Agriculture
2	Metal mining
3	Other mining
4	Coal
5	Crude oil and natural gas
6	Food and tobacco
7	Beverage
8	Textiles
9	Clothing and other fiber products
10	Wood products
11	Furniture
12	Paper and paper products
13	Printing and publishing
14	Chemical fertilizers
15	Basic chemicals
16	Plastic products
17	Chemical fibers
18	Chemical products
19	Medical and pharmaceutical products
20	Petroleum
21	Coking
22	Plastic products
23	Rubber products
24	Glass and glass products
25	Cement
26	Ceramic ware
27	Other non-metal mineral products
28	Pig Iron and crude steel
29	Steel pressing
30	Steel products
31	Nonferrous metal smelting
32	Nonferrous metal processing
33	Metal products
34	General industrial machinery
35	Special industrial machinery
36	Other general industrial equipment and parts

37	Office equipment
38	Household electronic and electrical apparatuses
39	Computers and accessories
40	Communication machines
41	Other electronic instruments
42	Electronic element and device
43	Generators
44	Other eletrical machinery
45	Car
46	Parts and accessories for cars
47	Other transport equipment
48	Instruments
49	Other manufacturing products
50	Construction
51	Public projects
52	Electricity, steam and hot wather production and supply
53	Water production and supply
54	Commerce
55	Finance, Insurance and real estate
56	Transport
57	Commuication and broadcasting
58	Offical business
59	Other public services
60	Other business services
61	Other personal services

Table B3 Other Studies on Pollution Content in Trade for China

Author	**Methodologies**	**Pollutants**	**Period**	**Findings**	**Consistency**
Antweiler (1996)	EIOA; Common tech	CO; SO_2;NO_2, Lead; Particulate matter; volatile organic compounds,	1987	Composite PTOT: 0.544	**YES**
Ahmad and Wyckoff (2003)	EIOA; Hetero tech	CO_2	1997	BETT>0	**YES**
Shui and Harriss (2006)	(EIO-LCA) software; Common tech Emission factors gauged for China	CO_2	1997-2003	BETT>0	**YES**
Umed (2006)	EIOA; US and CN IO	CO_2, SO_2, NO_x	1992, 1997	PTOT<1	**YES**
Wang et al. (2007)	Simple method; Common tech; IEA CO_2 emission per unit of GDP (country specific)	CO_2	2004	BETT>0	**NO**
Dean and Lovely (2008)	Simple method: Chinese industrial pollution intensities and annual trade data	COD; SO_2; smoke; Dust	1995-2004	COD, SO_2, Smoke: PTOT>1 Dust: PTOT<1	**Yes in terms of SO_2**

Diagram B1 Breakdown of Pollution Intensity

(Extended 2002 assumption 1)

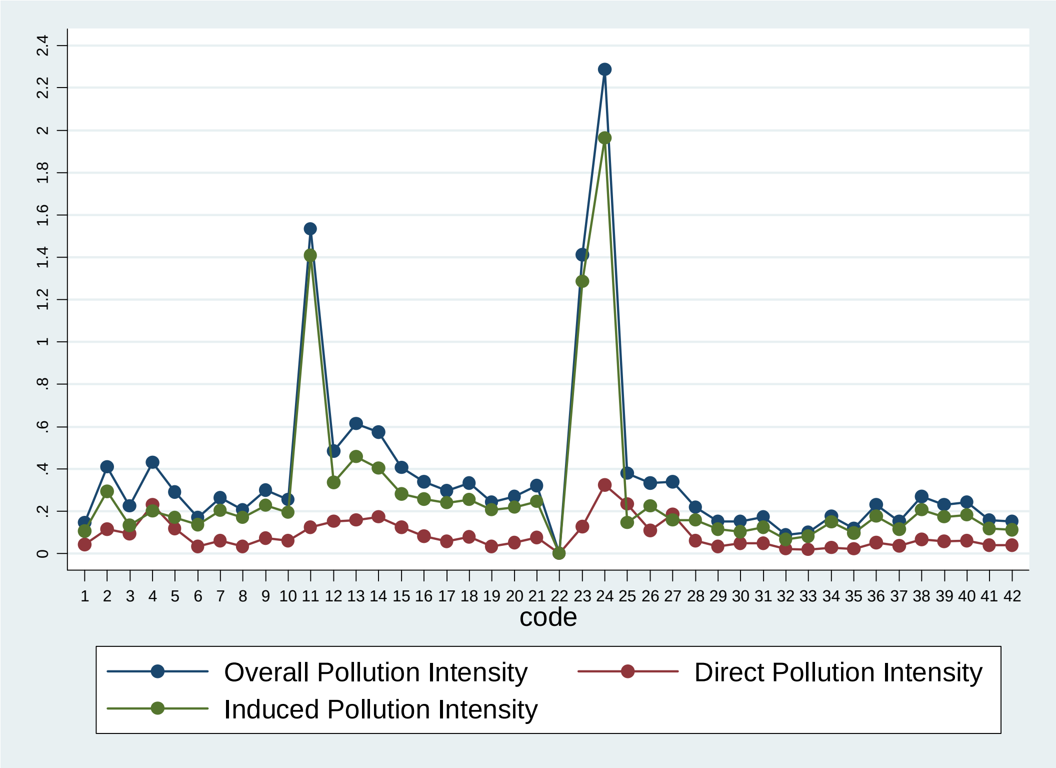


Diagram B2 Overall Pollution Intensity and Net Exports 1987

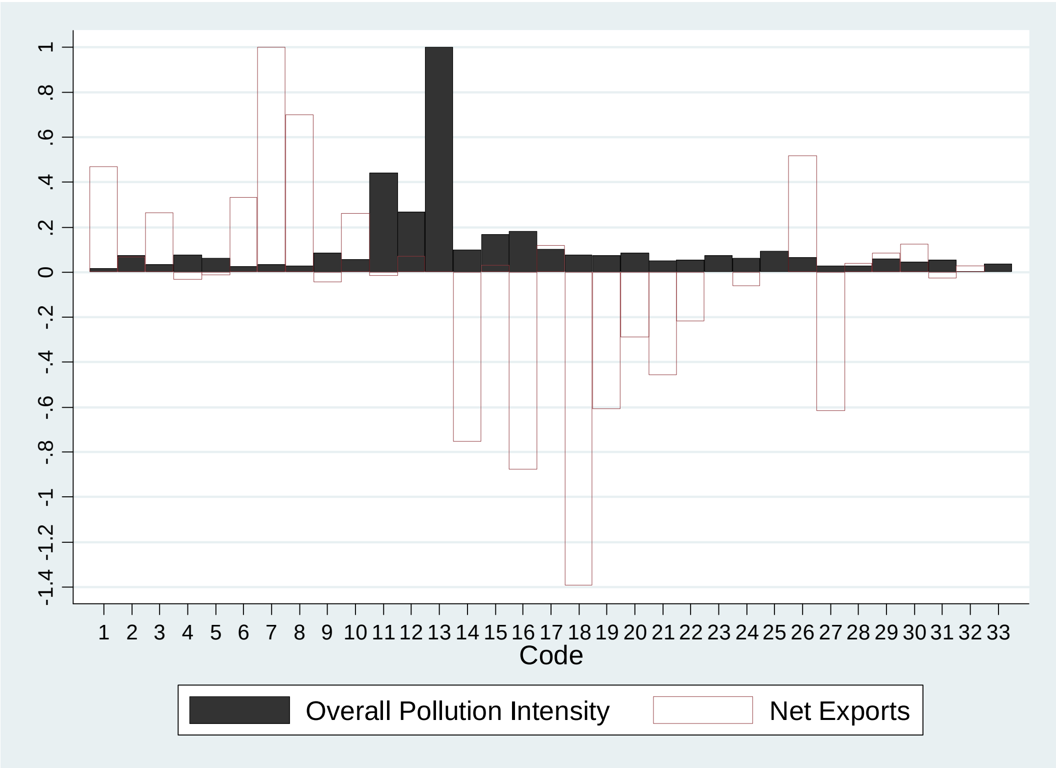


Diagram B3 Overall Pollution Intensity and Net Exports 1990

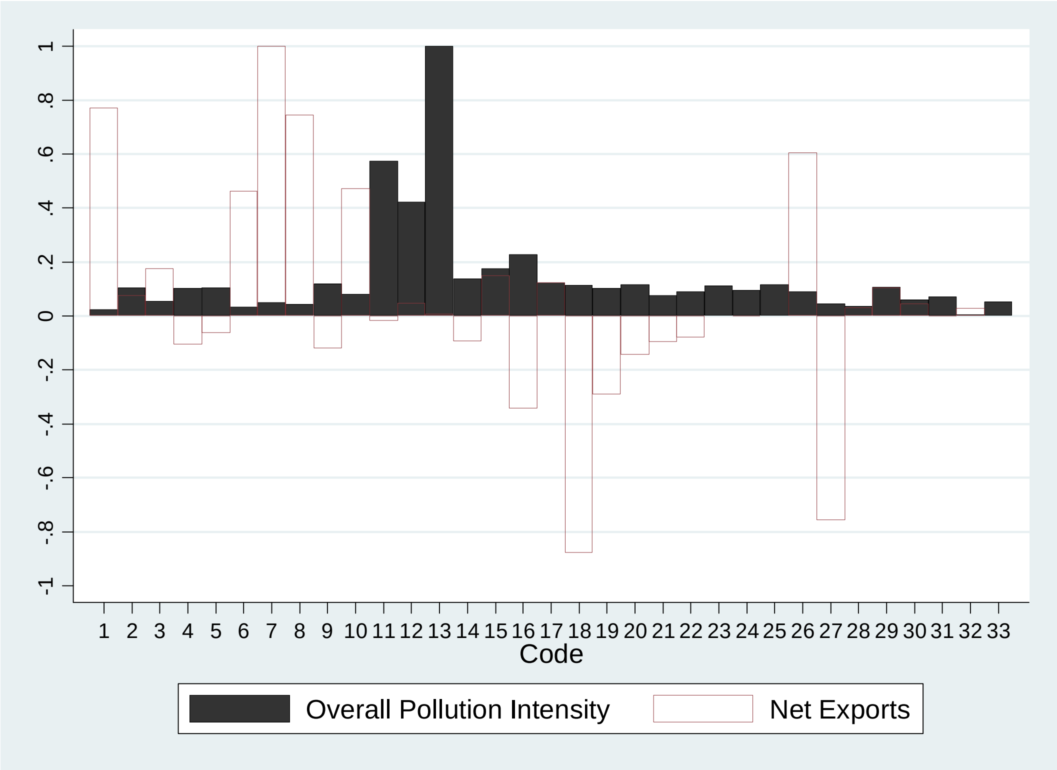


Diagram B4 Overall Pollution Intensity and Net Exports 1992

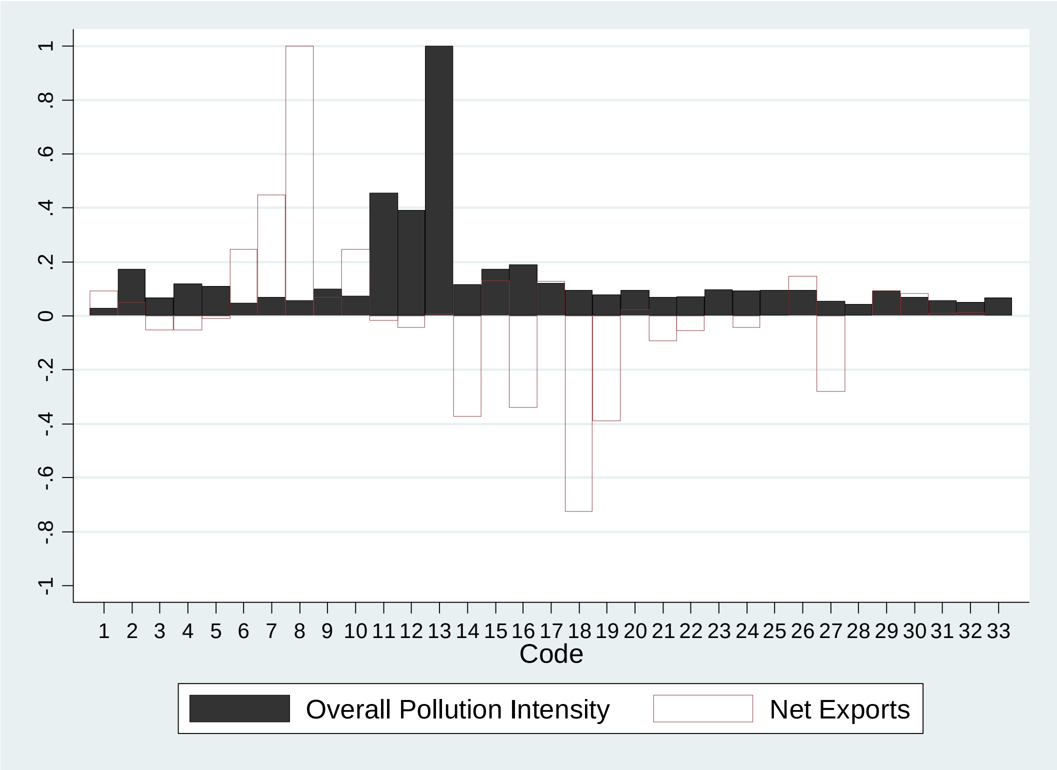


Diagram B5 Overall Pollution Intensity and Net Exports 1995

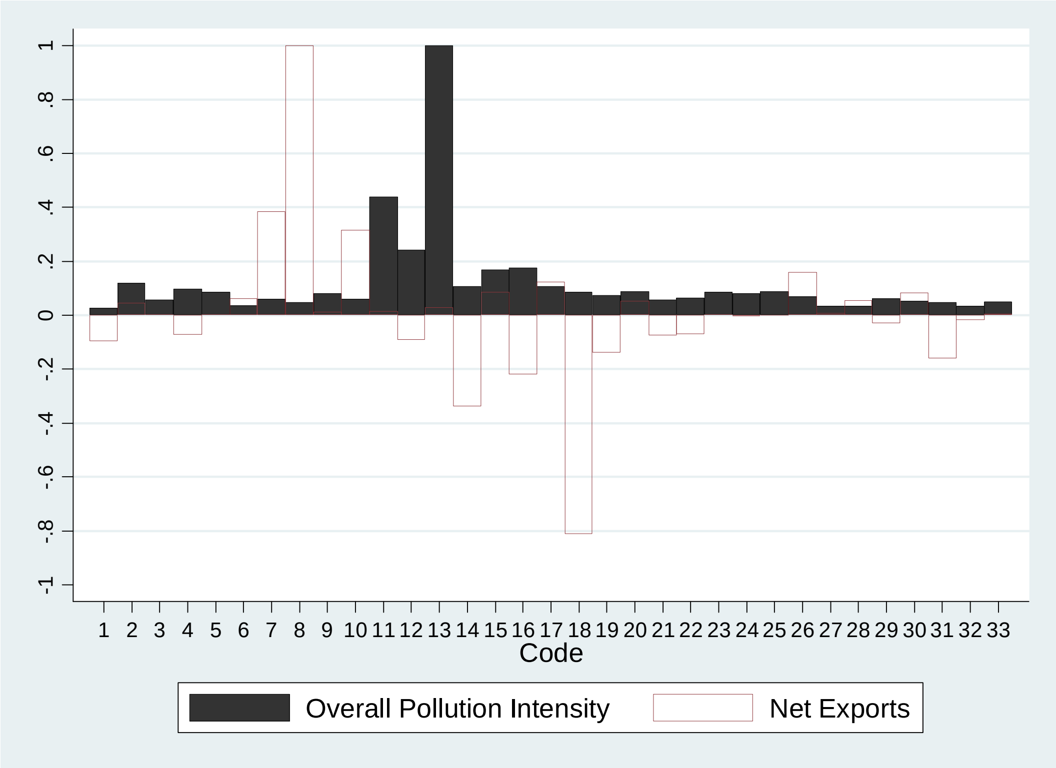


Diagram B6 Pollution Intensities of Exports and Imports (Commodity Trade)