TRADE GROWTH, PRODUCTION FRAGMENTATION, AND CHINA'S ENVIRONMENT

Judith M. Dean
Mary E. Lovely

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ABSTRACT

Trade growth for a relatively poor country is thought to shift the composition of industrial output towards dirtier products, aggravating environmental damage. China's rapidly growing trade and serious environmental degradation appear to be no exception. However, much of China's trade growth is attributable to the international fragmentation of production. This kind of trade could be cleaner, if fragmented production occurs in cleaner goods, or if China specializes in cleaner stages of production within these goods. Using Chinese official environmental data on air and water pollution, and official trade data, we present evidence that (1) China's industrial output has become cleaner over time, (2) China's exports have shifted toward relatively cleaner, highly fragmented sectors, and (3) the pollution intensity of Chinese exports has fallen dramatically between 1995 and 2004. We then explore the role of fragmentation and FDI in this trend toward cleaner trade. Beginning with a standard model of the pollution intensity of trade, we develop a model that explicitly introduces production fragmentation into the export sector. We then estimate this model using pooled data on four pollutants over ten years. Econometric results support the view that increased FDI and production fragmentation have contributed positively to the decline in the pollution intensity of China's trade, as has accession to the WTO and lower tariff rates.

Judith M. Dean
US International Trade Commission
Office of Economics, Research Div.
Washington, DC 20436
Judith.Dean@usitc.gov

Mary E. Lovely
Syracuse University
Maxwell School
Syracuse, NY 13244
melovely@maxwell.syr.edu

I. Introduction

China often receives attention both for its rapidly growing trade and its serious environmental degradation. China's trade with the world has risen dramatically between 1995 and 2005. In current dollars, the value of China's exports plus imports rose from $280.9 billion in 1995 to $1422.1 billion in 2005--a growth of about 406%. While major improvements have been made in water and air quality over the same period, China's State Environmental Protection Agency (SEPA) stated that "[t]he conflict between environment and development is becoming ever more prominent. Relative shortage of resources, a fragile ecological environment and insufficient environmental capacity are becoming critical problems hindering China's development," (SEPA, 2006).

Some of the large literature on trade and environment lends credence to the idea that trade growth and environmental degradation are causally related. The environmental Kuznets curve literature suggests that low income countries have relatively lenient environmental standards and hence a comparative advantage in pollution-intensive goods.[1] As a low-income country grows, environmental damage increases due to increased scale of production and a composition of output biased towards "dirty goods." However, higher incomes also generate pressure for more stringent environmental regulations. Since tighter regulations raise the cost of polluting and give producers incentives to find cleaner production techniques, this tends to reduce environmental damage.[2] For low income countries, the scale and composition effects are thought to outweigh the technique effect, implying that the net effect of growth is detrimental to the environment. Since trade growth raises incomes, it, too, contributes to these scale, composition and technique effects. Yet empirical evidence on the net effect of trade and environmental damage is mixed, with at least some studies (Dean, 2002; Antweiler, et al., 2001) finding evidence that the technique effect may be stronger than previously

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[1] The evidence on the existence of an environmental Kuznets curve is mixed and highly dependent upon time period, countries evaluated, and pollutants examined. Thus, there is no way to verify whether or not China is to the left or right of the turning point in the "inverted U." For surveys covering the broader literature on trade and environment, see Dean (2001) and Copeland and Taylor (2004).

[2] In addition, some would argue that increased FDI would imply greater environmental degradation, as firms in pollution-intensive industries may move to avoid more stringent environmental regulations at home. See Dean, Lovely, Wang (2007) for review of evidence and counterargument.

thought, leading to a net beneficial impact of trade growth on the environment.

China's integration with the world economy may not fit this conventional picture. Much of China's trade growth is attributable to the international fragmentation of production--the splitting of production processes into discrete sequential activities (fragments) which take place in different countries[3] (Chen, et al., 2004; Ping, 2005; Dean, Fung, Wang, 2008). China's trade statistics explicitly designate "processing imports" as imports of intermediate inputs to be used to produce products solely for export, and "processing exports" as those exports which use these imported inputs.[4] This trade alone accounts for about 56% of the growth in China's exports and 41% of the growth in China's imports between 1995 and 2005. In addition, a large part of this trade is attributable to foreign-invested enterprises (FIEs).[5] In 2005, about 84% of China's processing exports and imports were carried out by FIEs.

Trade arising from international production fragmentation could be cleaner than conventional trade. If highly fragmented industries (such as computers and other high-tech products) and the particular fragments within these products that China produces are relatively clean, then China's output and trade would shift toward cleaner goods as these activities expand. In addition, if the FIEs who carry out much of this trade in fragments produce using greener technologies than those used by domestic producers in China, production techniques within fragmented industries would become cleaner over time. In this way, both the composition and technique effects of trade growth may be favorable to China's environment.

This chapter explores these relationships using new evidence on the pollution content of Chinese trade. We first present evidence on the growth of trade and industrial emissions in China. Using official Chinese environmental data on air and water pollution from the State Environmental Protection Agency, we find that industrial emissions of primary pollutants have slowed or fallen over the last decade while trade has grown. Across most industrial sectors, the pollution intensity of production has also fallen. We then explore

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[3] See Arndt and Kierzkowski (2001) for discussion of the causes of fragmentation.

[4] Chinese trade statistics record two types of processing imports and exports: processing and assembly (where the foreigner retains ownership of imported inputs), and processing with imported inputs (where the importer acquires ownership of imported inputs).

[5] Chinese trade statistics record several types of FIEs: fully-funded enterprises (i.e., wholly-owned subsidiaries of foreign companies), equity joint ventures, and contractual joint ventures.

trends in the pollution intensity of Chinese trade. Building on highly disaggregated trade data from China Customs, we report new evidence that the pollution intensity of Chinese exports has fallen dramatically from 1995 to 2004. We use a counterfactual exercise to show that this decrease in the pollution intensity of trade is due partly to a shift in the composition of trade toward cleaner goods, but also to a shift in production technique toward cleaner processes.

Finally, we explore the possibility that production fragmentation and processing trade may have played a role in making China's trade cleaner. Building on the framework provided by Copeland and Taylor (1994), we develop a reduced form model of the pollution intensity of trade, incorporating standard determinants of a country's production mix, such as factor proportions, income per capita, and trade policy. We then incorporate a fragmented export sector, building upon the work of Feenstra and Hanson (1996). The impact of fragmentation on the pollution intensity of China's exports and imports is estimated using data on four pollutants over a ten year period. We find evidence consistent with the view that the increased role of processing trade and the extensive presence of foreign invested enterprises have both contributed to reducing the pollution intensity of China's trade.

II. An Overview of China's Environmental Quality and Regulation

A. Environmental Quality

Descriptions of China invite superlatives and this is certainly true of China's environmental problems. There are almost daily media reports of rivers and lakes poisoned by pollution and algal bloom, water tables dropping too low to meet basic needs, farmlands tainted by industrial pollution and fertilizers, and cities choking on smog.[6] With economic growth forecasts exceeding 10%, the associated growth in industrial and municipal wastes, vehicle emissions, agricultural run-off, and deforestation have led observers to doubt the sustainability of China's development path. Indeed, as Naughton (2007) notes, "The challenges of water availability, resilience of the natural environment, and atmospheric degradation and climate change are among

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[6] An excellent and informative example is the New York Times series, *Choking on Growth*, which reports on many aspects of China's environmental challenge. See http://www.nytimes.com/2007/08/26/world/asia/26china.html.

the most serious that China confronts."

China's environmental problems are not the result of current emissions alone. The accumulation of past pollution, the ability of the air, land, and water to refresh itself, and changes in settlement patterns are all reflected in today's environment. Even if all economic activity were halted today, China would face serious "pollution problems" for years to come. When thinking about the effect of economic activity on the environment, therefore, it is important to distinguish between emissions, the flow of pollutants into the environment, and ambient quality, the level of pollutants present at a specific point in time. Our analysis focuses on the former while most news reports focus on the latter.

To put our discussion of trade and emissions into perspective, it is useful to review briefly trends in China's ambient quality. Despite widespread awareness of China's recurrent environmental crises, it is difficult to obtain consistent evidence on environmental quality. Repeated measures of ambient quality are available only through SEPA and even official reports reflect changing measurement methods and definitions over time, as China's environmental regulation and monitoring capability have improved. The data used in this study are drawn from official Chinese sources. There are many problems with official Chinese data and environmental statistics are no exception. Nevertheless, there is no alternative set of data available. Moreover, these data provide systematic information to an area of research often dominated by anecdote.

Figure 1 provides summary data on the trend in water quality for China's seven major rivers drawn from SEPA's annual *State of the Environment* reports. From 2001 to 2005, there has been some improvement in water quality. The percentage of monitoring sections of the seven major rivers meeting a grade III quality standard or better rose from 30% to 40%, while the percentage considered to be highly polluted (grade V or worse than grade V) fell from 53% to 34% These data suggest that China has succeeded in raising the quality of its extremely polluted water to a more moderately polluted level, but has made little progress in raising much of its water to the higher grade standards. These summary measures, though, hide substantial variation in water quality in different segments of the rivers and in their tributaries. For example, the mainstream of the Yellow River is considered to be only lightly polluted while most of its tributaries are heavily polluted (SEPA, 2007). Freshwater lakes and reservoirs remain heavily polluted. In 2006, 48% of major lakes and reservoirs were listed as worse than Grade V implying that they are heavily polluted (SEPA, 2007). The most ubiquitous pollutant is readily degradable organic materials from industry and households, with industry's share of these pollutants falling from 50% to 38% by 2005 (SEPA, 2007).

National survey data summarized by the World Bank (2001) suggest that total emissions of major air pollutants (SO_2, soot, and dust) peaked in the mid 1990s. As shown in figure 2, SEPA reports that urban air quality continued to improve between 2000 and 2005. The percentage of cities with air quality rated Grade II (up to standard) or better rose from 37% to 52% during this period. Again there are indications that most of China's progress has been in reducing the extent of severe air pollution, as the percentage of cities with air quality worse than grade III fell from 33% to 11% Particulates are considered the most important pollutant affecting urban air quality, both in terms of frequency and health costs. Particulate emissions are heaviest in China's largest cities, including Beijing and Tianjin, due in part to the rapid growth of motor vehicle emissions in these areas. More than 80% of SO_2 and dust and most soot is attributed to industrial sources, which includes coal-fired power plants.

B. Environmental Regulation and Policy

The Chinese government has long recognized the need for environmental protection. In 1989 a legislative base for environment protection was created by promulgation of the Environmental Protection Law. This law authorized the Environmental Protection Bureau of the State Council to set ambient standards and waste discharge and emission standards. In 1984 the Bureau gained administrative independence as a separate office and its office staff size doubled. The Bureau was renamed the National Environmental Protection Agency four years later, its staff size again doubled, and it was given direct links to the State Council. In recognition of the increasing importance placed upon environment in the overall development plan, NEPA was renamed the State Environmental Protection Agency and given ministerial rank in 1998. Despite this rank, SEPA does not have a seat in the State Council and it remains less powerful than some other key ministries (OECD, 2005). It is considered to be underfunded and, with just 300 central staff, undermanned for the large portfolio it oversees.

SEPA is responsible for developing policies and programs at the national level. In each province, Environmental Protection Bureaus oversee compliance with national and local environmental regulations. These local Bureaus report to provincial administrators, which also oversee their funding. Recently, SEPA has acquired some say in the selection of provincial EPB heads. EPBs also exist at the prefecture or municipal, and district or county levels. EPBs report directly to upper level environmental administrators as well as to the government of a geographic area. This reporting system is often cited as a source of conflict for local EPBs who may face interference from local leaders. Lower level EPBs report to higher level EPBs, but the funding and supervision are provided by the province or lower-level administration (OECD, 2005).

China has a well-developed regulatory system with over 2,000 laws related to environmental protection. During the 1990s, China gave increasing emphasis to prevention and shifted responsibility to polluters to pay for environmental damage. A key policy instrument in this shift was the introduction of a discharge fee system, with fees based on the concentration of effluents. These fees are applied to industrial emissions across China, with most revenue accruing from fees for discharges of wastewater and waste gases. This system has been criticized on a number of dimensions. It is widely believed that the fees are only a fraction of the social cost of pollution and that the fees do not encourage abatement. Local EPBs can also issue permits that limit the quantities and concentrations of pollutants in an enterprise's emissions, set deadlines for pollution control, and close plants deemed dependent on "backward" technology.

More recently, the Criminal Code has been revised to provide for criminal sanctions for egregious harm to the environment (OECD, 2005). Environmental impact assessment has become routine for major economic projects and SEPA and EPBs can suspend or delay projects that do not meet environmental standards. In 1992 the Chinese government removed a number of sectoral and regional restrictions on FDI and decentralized approval (Lardy, 1994). New rules introduced in 1995 prohibit foreign investment that involves dangerous, polluting, or wasteful processes (Henley et al., 1999). [7]

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[7] SEPA also oversees a substantial program of pollution control, with 1.4% of GDP devoted to this purpose in 2003 (Naughton, 2007). They also engage in scientific projects and international cooperative agreements promoting "leapfrogging" development, among other activities (SEPA, 2007).

III. Trends in Chinese Industrial Emissions and Manufacturing Trade

A. Aggregate trends

In this chapter our interest is in the relationship between China's trade and China's environment, rather than the global environment. Hence, we focus on the primary pollutants which China uses to evaluate the condition of its own environment, rather than the greenhouse gases associated with global climate change. In the 10th Five Year Plan (2001-2005), the Chinese government stated explicit goals for the reduction of its water pollution, as measured by Chemical Oxygen Demand (COD) and its air pollution, as measured by sulfur dioxide (SO_2) and particulate matter (especially that generated by smoke and dust) (OECD, 2005). COD measures the mass concentration of oxygen consumed by chemical breakdown of organic and inorganic matter in water.[8] COD emissions account for the majority of industrial water pollution levies collected in China during this period. While emissions of other water pollutants are recorded in more recent years, they are generally positively correlated with COD. Industrial SO_2 emissions include the sulfur dioxide emitted from fuel burning and from the production processes on the premises of an enterprise. Industrial smoke (or soot) emissions include smoke emitted from fuel burning on the premises of an enterprise. Industrial dust emissions refer to the volume of dust suspended in the air and emitted by an enterprise's production processes.[9]

Figure 3 shows the trends in China's overall merchandise trade (billions of $US (2000)) and industrial emissions (billions of kilos) from 1995-2005. Trade data are Chinese official data obtained from China Customs. Industrial emissions data are from the *Chinese Environmental Yearbook* and *China Statistical Yearbook on Environment* (various issues). In Chinese official statistics, the industrial sector includes Mining, Manufacturing, and Production and Distribution of Electricity, Gas and Water.[10] Emissions data

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[8] *China Statistical Yearbook on Environment*, 2006, p. 207.

[9] *China Statistical Yearbook on Environment,* 2006, p. 208. This does not include indirect generation of dust caused by purchasing energy generated from power plants.

[10] Changes in Chinese industrial emissions should be fairly representative of air pollution emissions, since industry accounts for at least 80% of SO2, smoke, and dust emissions throughout the period. Chinese industrial water pollution emissions accounted for 60% of COD emissions at the start of the period. With emissions from households and services growing in importance, industry's share fell to only 40% by the end of the period.

prior to 1998 were recorded only for industrial enterprises at the "county level and above." After the "Investigation on Sources of Township Industrial Pollution," published in 1997, it was found that township and village industrial enterprises (TVIEs) were accounting for a growing percentage of emissions. Therefore, emissions data include these enterprises from 1998 onwards. In Figures 3 and 4 we have been able to include TVIE emissions for 1995 and for 1997. But the TVIE data are unavailable for 1996, so we treat 1996 as missing (indicated by the dashed lines).

The most remarkable trend in figure 3 is the dramatic and rapid increase in the value of China's merchandise exports plus imports over the period. At the same time, industrial emissions are generally falling. While figure 3 shows a small increase in SO_2 emissions over the period, emissions of COD, soot and dust show a slow but significant decline. This decline in industrial emissions is confirmed in the ten-year environmental review issued by SEPA (2006), and is also noted by the WTO (2006) and the OECD (2005). Figure 4 shows an index of trade and industrial emissions levels, with 1995 as the base year. By 2005, trade had increased nearly 300% in real terms over its 1995 value. Meanwhile annual industrial emissions of COD, smoke, and dust had declined to 56%, 46% and 40%, respectively, of their levels in 1995. In contrast, industrial SO_2 emissions rose after 1999 and were 17.5% above 1995 levels by 2005.

B. Trends in the composition of China's trade

To understand what is driving these aggregate trends, we first examine trends in the composition of China's trade. Because data on emissions by industrial sectors are readily available, but data for agricultural or service sectors are not, we limit our analysis to manufacturing trade. In 2005, manufacturing trade accounted for 97% of Chinese exports and 83% of Chinese imports. Table 1 shows the shares of exports and imports in 1995 and 2004, by 2-digit ISIC sectors in manufacturing. The Chinese trade data were aggregated to HS (6-digit) and then converted to ISIC Revision 3 using the official Chinese concordance.

Even at this rather aggregated level, table 1 reveals some dramatic shifts in the sectoral composition of Chinese trade over this time period. In 1995, textiles and apparel accounted for the largest shares of Chinese exports to the world. These shares fell by about a third by 2004, while the export share of office and computing machinery grew by a factor of five, and that of communications equipment more than doubled.

The largest shares of Chinese imports in 1995 were attributable to textiles and machinery. These shares fell by about 70 % and 40%, respectively, by 2004, while import shares in office and computing machinery and in communications equipment more than doubled.

The sectoral shift in the composition of China's trade is interesting not only because it is dramatic, but because the same sectors have shown increases in both export and import shares. This suggests that much growth has taken place in sectors where production is internationally fragmented, resulting in two-way trade in "fragments" at varying stages of production. One rough indicator of the degree to which industries are internationally fragmented is the share of processing exports (imports) in each sector's total trade. Textile and apparel exports had substantial shares of processing exports across sectors in 1995, which fell somewhat by 2004. In contrast, office equipment and computing and communications equipment had extremely high shares of processing exports in 1995, and these shares remained high in 2004. Similarly, table 2 shows a decline in the share of processing imports in textiles, and a contrasting rise in that share in communications equipment imports, though not in office and computing machinery imports. This evidence suggests that China's exports (and to a lesser extent imports) have become more concentrated in highly fragmented sectors, and that the degree of fragmentation in some of these sectors has grown over time.

C. Trends in industrial pollution intensity

To see the extent to which changes in production technology could be impacting emissions, we measure the pollution intensity of production by industry, from 1995-2004. We compiled data on emissions of the four pollutants at the industry level, as well as current value of output of the sampled enterprises, from the *Chinese Environmental Yearbooks* (Chinese editions). Pollution intensities were then calculated as emissions (kilos) per thousand yuan output (constant 1995 yuan) for 33 Chinese 2-digit "divisions," including 30 manufacturing industries and 3 utilities, in the Chinese 2002 industrial classification.[11] These pollution

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[11] We measure pollution intensity as emissions relative to the value of output because the trade data are also measured in terms of value and our main concern is to measure the pollution intensity of the trade bundle. For some analyses of industrial pollution intensity, a measure of emissions per unit of value added might be preferable. We are unable to express pollution intensity relative to value added because value-added data are not available at a sufficiently disaggregated level. A comparison of the two measures could reveal important, but unknown, differences. Because the

intensities are shown in appendix table A1. The appendix also provides a detailed explanation of these calculations, and the treatment of missing or aggregated data. In Table 2 we present these average water and air pollution intensities (in kilos per thousand yuan output (constant 1995 yuan)), mapped to the ISIC 2-digit sectors, for 1995 and in 2004.[12] Pollution intensities for manufacturing (ISIC 15-36) and for utilities (ISIC 40-41) are included in the table.[13] In each year, the three sectors with the highest pollution intensities are shown in bold for each pollutant.[14]

Of the manufacturing industries, the major source of water pollution is production of paper and paper products. A few others--food products and beverages, and wood products--show relatively high water pollution intensities, but these are far below that of the paper sector. Most industries show very low water pollution intensity. With respect to air pollution, non-metallic minerals (which includes cement) is by far the most SO_2-intensive, and among the top three in terms of smoke and dust. The other industries with high air pollution intensities include basic metals and paper (SO_2), paper and wood (smoke) and wood and basic metals (dust). But again these industries generally show much lower pollution intensities than non-metallic minerals. Most industries, in fact, show very low air pollution intensities. The utilities as a group are highly polluting. The water utility is second only to paper production in water pollution intensity. The electricity and gas utilities are the dirtiest sectors overall in terms of SO_2 and smoke.[15]

Table 2 also reveals two interesting trends. The first is that across nearly all sectors, the pollution

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emissions data are classified by economic activity, the numerator of these two measures should be similar as they are not affected by changes in the value of purchased intermediates used in the production process. However, the denominators will differ if an increase in purchased intermediates increases the value of output, thereby reducing pollution measured relative to total value but not relative to value added.

[12] The official Chinese concordance maps the Chinese 2002 industrial classification at the 4-digit level to ISIC revision 3 at the 4-digit level. Though some ISIC 2-digit sectors correspond to a single Chinese 2-digit "division," some correspond to either multiple Chinese divisions, or to one division plus several 4-digit lines from other divisions. Thus, the average pollution intensities for the ISIC 2-digit sectors in table 2 generally represent a production-weighted average of the pollution intensity of multiple Chinese divisions. The production weights were constructed using Chinese gross industrial output data at the 4-digit level from http://www.chinadataonline.org. Since not all sample years were available, weights were constructed using 2004 data.

[13] ISIC 37 (Recycling activities) is omitted. See appendix for discussion.

[14] Because there are fewer ISIC 2-digit sectors than Chinese divisions, there is some variation between the highest pollution intensities in table 2 and table A1.

[15] ISIC Revision 3 groups the electricity and fuel gas utilities into ISIC 40, and as a result, the dust intensity for ISIC 40 looks quite low. But fuel gas production and supply has the second highest dust intensity across Chinese divisions.

intensity of production has fallen over time. This is true for all four pollutants. Even the water and energy utilities show improvement over the period. Thus, there is some evidence of a shift toward cleaner industrial production techniques in China. The second trend is that China's trade does appear to be shifting toward cleaner sectors over time. Although trade in 1995 was not concentrated in the highest polluting sectors, textiles and leather products were somewhat high in terms of water pollution intensity, and certainly not the lowest in terms of SO_2 and smoke intensity. Though these industries show cleaner production techniques by 2004, they remain significantly more polluting than office and computing machinery and communications equipment. The latter sectors' pollution intensities were low in 1995 and extremely low as of 2004.

The pollution intensities in table 2 include direct water and air emissions from production processes within each 2-digit sector and indirect air emissions from fuel burning on enterprise premises. For a complete assessment of indirect emissions we would ideally use an input-output table to capture emissions generated by (i) use of domestically-produced intermediates in other 2-digit ISIC sectors, and (ii) use of energy and water purchased from utilities. However, two main issues impede such an assessment. First, goods exported under the processing regime use more imported intermediates--and, therefore, less domestically produced intermediates--than those exported under the normal regime. Thus, the input-output table would have to distinguish imports of final goods from imports of intermediates, and then distinguish imported intermediates used for processing exports from those used for normal exports. Second, indirect emissions from fuel burning on site are already included in our pollution intensities. Thus, input-output coefficients reflecting energy demand would have to be adjusted to net out on-site supplies.

The official Chinese input-output table does not address either of these issues. In recent work, Dean, Fung, Wang (2008) provide an improved method for identifying imported intermediates and for splitting the Chinese IO table between processing exports and normal exports for 123 sectors for 1997 and 2002.[16] In theory this could be used to address the first issue discussed above for two years in our sample. However, differences between the use of domestic intermediates (including energy and water) for processing vs. normal

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[16] See Dean, Fung, Wang (2008) for a discussion of advances over earlier analyses by Chen, et al. (2004) and Ping (2005).

exports would only emerge after rebalancing, since no separate data are available. There appear to be no data available to address the second issue. This is a critical drawback to any calculation of indirect emissions, since table 2 shows that Chinese utilities are highly polluting industries. Therefore, in the present analysis, we use the pollution intensities in table 2 to assess changes in the pollution intensity of Chinese trade.

IV. The Pollution Intensity of Chinese Trade

If the popular wisdom were correct, we would expect China's continuing trade liberalization, particularly after its 2001 WTO accession, to lead to increased specialization in "dirty goods." This composition effect, along with increased scale of production would be expected to worsen emissions and lead to "dirtier" trade than in earlier years (*cet. par.)* However, thus far we have presented at least superficial evidence that trade has shifted toward cleaner industries, and that industrial production has become cleaner over time. In addition, this evidence suggests that production fragmentation may have played a role in these trends. In the evidence we present below, we find:

- Chinese exports are ***less*** water pollution intensive, and generally ***less*** air pollution intensive, than Chinese imports.
- ***Both*** Chinese exports and imports are becoming cleaner over time.
- The cleaner trends in exports and imports are driven by ***both*** composition and technique effects, with the latter being the strongest.
- Processing trade is indeed cleaner than ordinary trade.

To measure the pollution intensity of Chinese trade, we bring together the Chinese manufacturing pollution intensities discussed earlier and the Chinese trade data. Early studies of the pollution intensity of US trade (Walter, 1973; Robison, 1988) did not have industrial emissions data, so had to rely on estimates of environmental control costs (e.g. abatement capital and operating costs and R&D) to calculate pollution intensity by industry. More recently, Ederington, et al. (2004) made use of US industrial emissions data for a single year, and changes in the composition of exports and imports over time, to construct changes in the pollution intensity of US exports and imports. While this was a significant advance, the lack of time series emissions data confined the observed changes over time to composition effects. In a recent paper Levinson (2007) uses several years of US industrial emissions data to discern the relative importance of composition and technique effects in the pollution intensity of US trade.

Here we use the annual Chinese pollution intensities across industries and annual trade data to calculate an export- (import-) weighted average pollution intensity for aggregate exports (imports) for each of the 11 years in the sample (1995-2004). Using the official Chinese concordance, we map the Chinese pollution intensity for each Chinese division to the 4-digit ISIC lines corresponding to that division.[17] This pollution intensity is then weighted by the share of manufacturing exports (imports) corresponding to that 4-digit ISIC line, and summed to yield an export (import)-weighted average pollution intensity for each year.

Figure 5 shows that both exports and imports became steadily cleaner throughout the period. By 2004, the water pollution intensity of exports had fallen by about 84% while that of imports had fallen by 89%, compared to 1995 levels. The drop in air pollution intensity was almost as dramatic, with export (import) SO_2 intensity falling by 75% (78%), smoke intensity by 75% (80%), and dust intensity by 73% (74%).[18] Interestingly, both Ederington, et al. (2004) and Levinson (2007) find evidence that US exports and imports also have become cleaner over time.

Chinese exports also appear to be much cleaner than Chinese imports. In 1995, had Chinese imports been produced in China, they would have generated about 70% more COD emissions per thousand yuan than Chinese exports. This difference diminishes over time, but remains throughout the period. Chinese exports are also less SO_2-intensive, and less smoke-intensive, than Chinese imports during 1995-2004, though these divergences are less dramatic than the water pollution case. Only if pollution intensity is measured with respect to dust emissions, do we find Chinese exports dirtier than imports.

To understand the relative role of composition and technique effects in generating these trends in

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[17] In the very few cases where several Chinese divisions map to a single ISIC 4-digit line, a production weighted pollution intensity is assigned. As before, production weights are constructed from the 2004 Chinese 4-digit level gross industrial output value data from China Data Online.

[18] The peak in dust emissions intensity is largely due to the inclusion from 1998 onwards of emissions from TVIEs. Because TVIE emissions data are unavailable at the sectoral level, the yearly industrial pollution intensities in 1995-1997 do not include TVIEs.

pollution intensity, we conduct a counterfactual experiment. We recalculate the pollution intensity of both aggregate exports and aggregate imports, assuming the pollution intensity of sectoral output remained at its 1995 levels. These counterfactual pollution intensities, shown by the dashed lines in figure 5, represent the change in pollution intensity of exports (imports) if only the composition of traded products had changed over time.

For all four pollutants, figure 5 shows that changes in the composition of trade did imply both cleaner exports and imports. However, in every case, these composition effects account for a relatively small proportion of the observed changes in the pollution intensity of trade. This suggests that China's cleaner production techniques have been the most important force behind cleaner trade. It should be noted that with pollution intensity data only available at the Chinese 2-digit level, the composition (technique) effect could be understated (overstated) in figure 5. A change in the composition of trade among activities *within* a division could lead to lower pollution intensity, but would be misattributed in our data to a technique effect.[19] While this is certainly possible, a closer look at the variation in the trade data suggests that within division changes in the composition of trade are not likely to be large enough to reverse the result. Interestingly, Levinson (2007) also finds evidence that technique effects are more important than composition effects in explaining the falling pollution intensity of US trade.

Because table 1 shows a shift in the composition of China's trade toward highly fragmented manufacturing sectors, and because table 2 suggests that these sectors are relatively low polluters, we examine more closely the pollution intensity of processing trade. Since the Chinese industrial pollution data are not differentiated by customs regime, the export- (import-) weighted pollution intensities for processing trade differ from those for overall trade solely due to the composition of products traded under the processing regime. As figure 6 shows, many of the trends in the pollution intensities for overall trade are also true for processing trade. Processing exports appear to be cleaner than processing imports with respect to all pollutants. Processing exports and imports also both show downward trends in pollution intensity during the

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[19] We are indebted to Arik Levinson for this observation.

period. Counterfactual results (not shown) also suggest that once again, composition effects are responsible for a small share of the decline in pollution intensity over time.

However, figure 6 also reveals that China's processing exports are cleaner than China's overall exports. The average COD, SO_2 and smoke intensities of processing exports are about 70% that of overall exports in 1995. The dust intensity of processing exports is even lower—only about 50% that of overall trade. Though some of these differences diminish over time, processing exports continue to have significantly lower pollution intensities than overall exports across all four pollutants throughout the period. This evidence is suggestive that the increase in China's processing exports has implied a composition effect that is favorable toward China's environment. This effect might be further magnified if the firms engaged in processing trade (largely foreign-invested firms) actually produce with cleaner techniques than average firms.

V. The Role of Fragmentation and FDI in Explaining the Pollution Intensity of Chinese Trade

To explore the role that production fragmentation and foreign investment play in the changes we observe in the pollution intensity of China's trade, we develop a model that embeds China into the global production network. Our model is tailored for the Chinese context in that it recognizes the magnitude of foreign investment and its effects on the composition of trade. The framework we use draws upon the structural model of pollution developed by Copeland and Taylor (1994), and the outsourcing model developed by Feenstra and Hanson (1996). We first consider the supply of pollution to identify the determinants of pollution regulation. Next, we examine the demand for pollution, first considering the pollution intensity of exports in a simple two-sector model without fragmented production and then adding a fragmented export sector. We use these models to explore the impact of foreign investment and trade liberalization on the pollution content of trade. Our goal is to derive several reduced form models of the determinants of the pollution intensity of Chinese trade, which we then test empirically.

A. Pollution Supply

We follow Copeland and Taylor (2003) in modeling the supply of pollution as the result of government behavior that maximizes the utility of a representative citizen:

$$V = u(I / p) - \gamma D. \tag{1}$$

Indirect utility is a function of real income, *I/p*, and the level of environmental damage, *D*. The government levies a pollution tax, τ, to induce the utility-maximizing level of damage, taking as given world prices, trade policy, and production possibilities. The GNP function gives the maximum value of national income as a function of domestic prices, the pollution tax rate, and vector of factor endowments. Consequently, real income for the representative citizen can be expressed as $\frac{I}{p} = \frac{G(p,\tau,v)}{Lp}$, where *p* is a price index and *L* is the number of citizens.[20] Maximization of (1) yields the Samuelson rule for public good provision: the government sets the pollution tax equal to the sum of marginal damages across all citizens. Marginal damage measures the willingness to pay for reduced emissions and it reflects the marginal rate of substitution between emissions and income. Given the indirect utility function (1), the pollution tax rate chosen is:

$$\tau = -L\frac{V_D}{V_I} = \frac{Lp\gamma}{u'(I / p)}, \tag{2}$$

where the right-hand side gives the marginal damage from pollution.[21] Using equation (2), we express the endogenous pollution tax as $\tau(L, p, I)$.

B. Pollution Demand without Production Fragmentation

We begin with the simplest model of production and trade. This model serves as an alternative to a second model, presented below, that explicitly incorporates export processing with imported intermediate inputs. We consider a two-sector model of a small, open economy. China is endowed with sector-specific capital and effective labor (*E*), which depends on the human capital of its labor force: $E = A(H)L$. The import-competing sector, *M*, uses effective labor and sector-specific capital and it serves as numeraire. Each unit of *M* produced releases one unit of pollution emissions.

The export sector produces Good Y using effective labor and sector-specific capital (K_Y). Effective

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[20] Pollution tax revenue is counted in *G* as a return to *D* and it is assumed to be rebated to citizens lump sum.

[21] Because we have adopted a specification in which the marginal disutility of pollution is constant, the pollution supply curve is horizontal. See Copeland and Taylor (2003) for further discussion and alternative specifications.

labor may also be used for abatement of the pollution emissions (*D*) created in the production process. Following Copeland and Taylor's (2003) form for abatement, we may express the production function for *Y* treating emissions as an input:

$$Y = \left[E_Y{}^{1-\beta} D_Y{}^{\beta} \right]^{\theta} K_Y{}^{1-\theta}, \tag{3}$$

where $0 < \beta < 1$. The relative domestic price of *Y* is $p = \delta p^*$, where $1/\delta$ is a measure of trade frictions and p^* is China's terms of trade. We use (3) to solve for the pollution intensity of export production, e_Y:

$$e_Y \equiv \frac{D_Y}{pY} = \frac{\beta\theta}{\tau}. \tag{4}$$

We use (4) to create our first estimating equation for the pollution intensity of Chinese exports. In doing so, we note that the pollution intensity given by (4) depends on the pollution intensity of China's export production, as measured by the term, β. As Copeland and Taylor (2003) discuss, differences across countries in factor abundance interact with regulatory differences to determine the pattern of trade. These considerations lead to an expression for the pollution intensity of Chinese exports of the form

$$e_Y = e_Y(K, H, L, \tau) = e_Y(K, H, L, I, p^*, \delta). \tag{5}$$

In this expression we have replaced the pollution tax rate with its determinants, based on (2). Thus, the pollution intensity of exports can be estimated as a function of Chinese factor endowments, its real income per capita, its terms of trade and its trade frictions.

If pollution intensity rises with the capital intensity of production, we would expect China's capital-labor ratio to be positively related to the pollution intensity of its exports but negatively related to the pollution intensity of its imports.[22] Because an increase in real income raises the level of the pollution tax, we expect the pollution intensity of exports to fall as China's real income rises. The terms of trade and trade frictions have ambiguous effects on pollution intensity. Improved terms of trade imply an increase in real GDP and, hence, a higher domestic pollution tax, reducing *e*, but a higher relative price for exports raises the

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[22] It is common to assume that pollution intensity rises with the capital intensity of production. Copeland and Taylor (2003) provide some evidence for the case of SO_2.

production value of factors used in abatement, raising *e*. If this latter consideration dominates, we would expect improved terms of trade and reduced trade frictions to raise the pollution intensity of China's exports.

C. Pollution Demand with Production Fragmentation

As an alternative to the simple two-sector model above, we consider a model with two export sectors. China is treated as a small economy relative to an advanced trading bloc (A). The first sector produces "ordinary" exports, those that are produced with domestic inputs, using the production technology given by (3). The "processing" sector produces a set of goods that are intermediate inputs for a single final good. This final good is costlessly assembled from a continuum of intermediate inputs, indexed by $z \in [0,1]$. Inputs are produced using effective labor, capital specific to the processing sector, and pollution discharge. Input production technology varies by the amount of labor used relative to the emissions created during production. We adopt a simple functional form for production technology of input z:

$$x(z) = \left[E(z)^{1-\alpha(z)} D(z)^{\alpha(z)} \right]^{\theta} K(z)^{1-\theta}. \tag{6}$$

We also restrict $\alpha(z) \in \left[\underline{\alpha}(z), \overline{\alpha}(z) \right], 0 < \underline{\alpha} < \overline{\alpha} < 1,$ and $0 < \theta < 1$. We assume that ordinary export production is more pollution intensive than processing export production, implying that $\beta > \overline{\alpha}$.

Intermediate producers consider the price of labor, capital and pollution discharge when choosing a production technique. The price of labor, w, measures the wage per effective labor unit, thereby accounting for labor quality differences across countries. The rental price of capital is given by *r*. If firms were unregulated, they would always choose to discharge as much as possible to economize on labor. However, China levies a pollution tax, τ, according to (2), and this tax is effective in the sense that firms abate some pollution. Given these factor prices, the firm's labor and discharge combination that satisfies cost minimization is:

$$\frac{w}{\tau} = \left(\frac{1-\alpha(z)}{\alpha(z)} \right) \frac{D(z)}{E(z)}. \tag{7}$$

Because (7) implies that the parameter $\alpha(z)$ determines how pollution discharge varies among intermediates producers, $\alpha(z)$ provides a measure of pollution intensity. We can order the intermediates in order of decreasing pollution intensity to obtain $\alpha'(z) < 0$.

To determine the pattern of trade between China and the advanced countries, we examine how unit production costs vary across intermediates. The unit cost of producing one unit of input *x* in country i is given by

$$c(w_i, \tau_i, r_i; z) = \kappa(z) w_i^{(1-\alpha(z))\theta} \tau_i^{\alpha(z)\theta} r_i^{1-\theta}, \tag{8}$$

where $\kappa(z)$ is an industry-specific constant. Input z is produced in an advanced country if $c(w_A, \tau_A, r_A; z) < c(w_C, \tau_C, r_C; z)$.

We assume that labor in the advanced bloc has high human capital levels and, thus, it is more productive than labor in China. The pollution tax levied in the advanced countries exceeds the rate set in China, such that $\frac{w_A}{\tau_A} < \frac{w_C}{\tau_C}$. Given these relative factor prices and assuming for the moment that rental rates are the same in both countries, input z would be produced in the advanced bloc if

$$\omega \equiv \frac{w_A}{w_C} \leq \left(\frac{\tau_C}{\tau_A} \right)^{\alpha(z)/(1-\alpha(z))} \equiv T(z). \tag{9}$$

With $\tau_A > \tau_C$ and $\alpha'(z) < 0$, $T(z)$ must be increasing in z. The advanced bloc's cost advantage increases as the pollution intensity of production decreases. For a given relative wage rate, ω, the $T(z)$ locus determines a critical industry z^* such that China has lower costs than the advanced bloc in the range of inputs indexed by $z \in [0, z^*)$ while the advanced bloc has lower costs in the range $z \in (z^*, 1]$.

Now we assume that the rental rate of capital is not the same in both countries and that instead, $r_A < r_C$. Because capital's cost share is the same across all goods, this rental differential lowers the cost of production in the advanced countries across the full range of intermediates. To consider an equilibrium with some trade in intermediates, we assume that despite its lower rental rate the advanced bloc has a cost disadvantage for intermediates more pollution intensive than input z^*, defined as that input for which

$c(w_A, \tau_A, r_A; z) = c(w_C, \tau_C, r_C; z)$. Figure 7 shows the minimum cost locus for China as CC and for the advanced bloc as AA.[23] While the slope of each locus depends on the underlying production functions, it can be shown that they are upward sloping.

The pollution intensity of this fragmented sector depends on which inputs China produces; that is, it depends on the value of z*. Based on the production functions (6), total discharge from the X sector is

$$D = \int_0^{z^*} D(z)dz = \frac{\theta}{\tau}\int_0^{z^*} \alpha(z)p(z)x(z)dz. \tag{10}$$

For simplicity, we assume that demand by the final good producer for each input is a constant share of total world expenditure and that, as a small country, China has a negligible impact on world income.[24] Using this assumption, $p(z)x(z) = \varphi(z)I^W$, in equation (10) leads to an expression for the pollution intensity of the fragmented sector:

$$e_X = \int_0^{z^*} \frac{D(z)}{p(z)x(z)} \frac{p(z)x(z)}{\int_0^{z^*} p(z)x(z)dz} dz = \frac{\theta}{\tau\int_0^{z^*} p(z)x(z)dz} \int_0^{z^*} \alpha(z)\varphi(z)I^W dz \tag{11}$$

Equation (11) allows us to express the pollution intensity of the processing sector as a function of the capital share of export output $(1-\theta)$, the pollution tax, τ, and the critical value, z*. When the capital intensity of processing exports rises, the average pollution intensity of these exports falls. Similarly, when the pollution tax rises, the average pollution intensity of processing exports falls. Lastly, an increase in the critical value, z*, reduces the average pollution intensity of the export processing sector because $\alpha(z)$ is a decreasing function of z. It is interesting also to note that an increase in z* reduces the pollution intensity of the inputs imported from the advanced countries for processing. Thus, when the range of inputs produced in China expands, the pollution intensity of both processing exports and processing imports declines.

As discussed above, the critical value, z* depends on the cost of intermediates production in China,

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[23] Feenstra and Hanson (1996) introduce a similar diagram to illustrate the fragmentation of production between the United States and Mexico.

[24] Copeland and Taylor (1994) also assume that budget shares are constant in their model, but they consider two countries large enough to affect international markets.

$c(w_C, \tau_C, r_C; z)$. Therefore, z* depends on all determinants of factor prices for the processing sector. These determinants are the terms of trade and the level of trade frictions, the determinants of the pollution tax rate, and all factor endowments. As discussed in a previous sector, foreign investment has been skewed toward those sectors that process and assembly imported intermediates. Therefore, we separate the capital stock into domestic (K^d) and foreign owned capital (K^f), allowing us to express the pollution intensity of the export processing sector as:

$$e_X = e_X(K^d, K^f, H, L, p^*, \delta, R). \qquad (12)$$

The pollution intensity of the whole export bundle is a weighted average of the pollution intensity of ordinary exports and the pollution intensity of processing exports. Using (5) to express the pollution intensity of ordinary exports and (12) to express the pollution intensity of processing exports and letting S_X denote the share of total exports that are processing exports, the pollution intensity of China's trade bundle is:

$$e = S_Y e_Y + S_X e_X = e_Y + S_X(e_X - e_Y) = e(K^d, K^f, H, L, p^*, \delta, R, S_X), \qquad (13)$$

where we have used the fact that $S_Y + S_X = 1$. Because we have assumed that $e_X < e_Y$, an increase in the processing share of exports obviously reduces overall export pollution intensity, *ceteris paribus*.

Foreign capital flows primarily to the export processing sector, reducing its cost of capital. Figure 7 can be used to illustrate the effect of this capital inflow on China's input competitiveness. At constant wages and pollution tax, the curve labeled CC shifts down, causing z^* to rise from z_1^* to z_2^*. With the pollution tax unchanged, there is no change in the pollution intensity of any intermediate. However, the capital inflow pulls labor into the processing sector, raising its share in exports. Moreover, because China now produces intermediates that are less pollution intensive than any it produced before, the average pollution intensity of China's processing exports falls.[25] Likewise, the pollution intensity of China's processing imports falls

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[25] There will also be feedback effects, which we do not discuss here. First, increased foreign investment may raise domestic wages, but this wage effect cannot overturn the direct effect of foreign investment. Second, higher real per capita income implies a higher pollution tax, reinforcing the direct effect by further reducing pollution intensity.

because China now imports a narrower set of inputs and this set is, on average, cleaner than before.

Foreign investment may reduce export pollution intensity through another channel, which we have not formally modeled, even if we hold the processing share of exports fixed. Foreign investment often involves the use of new capital equipment and new production techniques. In particular, investment from high-regulatory-standard countries may transfer new pollution control methods to the host country as investors use technology and techniques that they have developed within the context of stringent pollution regulation.[26] If foreign investors bring this sort of "technique effect" with them, the pollution intensity of China's exports should be negatively associated with the level of foreign capital, even when the share of processing exports is held constant.

VI. Estimating the Determinants of the Pollution Intensity of China's Manufacturing Trade

How well does the previous model of production fragmentation and foreign investment explain the changes in the pollution intensity of Chinese exports and imports shown in figure 5? To find out, we begin with the simple model expressed in equation (5), in which there is no fragmentation and FDI plays no distinct role. We then consider the model expressed in (13), which incorporates both ordinary and fragmented trade. Lastly, we allow for the endogeneity of fragmented trade and the explicit influence of foreign investment.

A. Econometric Specification

Since the pollution intensity of exports (imports) in figure 5 is linear in logs, equation (5) could be estimated by pooling the data on the four pollutants over the period 1995-2004, and adding pollutant-specific fixed effects and a linear time trend:

$$\ln e_{it}^{j} = \alpha_i + \beta_1 \ln K_{it} + \beta_2 \ln L_{it} + \beta_3 \ln p_{it} + \beta_4 \ln \delta_{it} + \beta_5 \ln R_{it} + \beta_6 \ln trend_{it} + \varepsilon_{it}$$

(where j is exports or imports, i is pollutant, and t is time). However, several difficulties arise with this approach. With this small sample of annual observations, the introduction of four additional variables (fixed effects and a trend) reduces the degrees of freedom substantially. In addition, recent literature suggests that

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[26] This possibility is consistent with evidence presented in Dean, Lovely, and Wang (2007) on the location decisions of foreign investors. While provincial variation in pollution taxes influenced the location of Chinese investors, no effect was found for OECD investors.

there are many unresolved issues in the construction of reliable data on the Chinese capital stock.[27] Finally, some of the macroeconomic explanatory variables in the model may be non-stationary. An alternative approach which addresses all three concerns is to estimate a first-differenced specification of the model in equation (5):

$$\Delta \ln e_{it}^{j} = \gamma + \beta_1 \Delta \ln K_{it} + \beta_2 \Delta \ln L_{it} + \beta_3 \Delta \ln p_{it} + \beta_4 \Delta \ln \delta_{it} + \beta_5 \Delta \ln R_{it} + \eta_{it} \qquad (5)'$$

where Δ indicates first difference.

Equation (5)′ is estimated using pooled data on COD, SO_2, smoke and dust intensity of exports (imports) at the national level, from 1995-2004. After differencing, this yields a small panel of 36 observations. The estimation method is GLS with cross-section weights, to correct for pollutant-specific heteroskedasticity. It might be reasonable to assume that the pollution intensity of trade responds differently across pollutants. Unfortunately, the limited sample size prevents us from using a varying coefficients model to explore this possibility. It might also be reasonable to assume that there is contemporaneous correlation across the pollutants in the sample. A change in the environmental regime, or a technological change which affects several pollutants simultaneously, could cause error terms to be correlated across pollutants in a given year. To address this issue, specifications of (5)′ were also estimated using OLS with panel-corrected cross-section standard errors (PCSE), which are robust to both cross-section heteroskedasticity and contemporaneous correlation. A comparison of the results allowed us to assess the importance of contemporaneous correlation, and the robustness of our results to an alternate estimation method. We found little difference in the results and so present only the GLS estimates.[28]

Data on all explanatory variables except the tariff and trade variables are from the World Bank, *World Development Indicators*, 2007. These data are shown in Table 3. The log difference in the capital stock is proxied by gross capital formation (% of GDP), while the log difference in the total labor force and in real

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[27] See the discussion of published data, previous methods of measurement, and recent innovations by Holz (2006), and the response by Chow (2006).

[28] Because of the small sample size, not all specifications could be estimated using PSCE. Results are available from the authors upon request.

GDP per capita are calculated directly from the data.[29] In this simple model, investment is not differentiated by source, nor labor supply by skill level. The log difference in relative prices is proxied by the difference in China's net barter terms of trade, where the latter is defined as the ratio of the export price index to the import price index, measured relative to the base year 2000. The data used to calculate the log difference in tariffs are China's simple average MFN tariffs (ad valorem equivalent) taken from the UNCTAD TRAINS database, via WITS.[30]

B. Estimating the Standard Model

Table 4 presents the results of estimation of equation (5)′ for exports in column (1). These results support some of the predictions discussed above. Ignoring the role of processing trade, an increase in the capital-labor ratio increases the pollution intensity of exports, suggesting that capital and pollution may be complements in production. Real GDP per capita--the proxy for stringency in environmental regulations—is negatively related to the pollution intensity of exports, though the impact is not significant. Trade liberalization appears to be favorable for China's environment. A fall in China's average tariff is associated with a fall in the pollution intensity of exports. Since China's tariffs actually fell by about 75% during this period, this suggests that trade reform may have contributed significantly to China's cleaner trade. In addition, China's entrance into the WTO in 2001 also seems to have been associated with a significant reduction in the pollution intensity of China's exports. Finally, though the impact of a change in the terms of trade is indeterminate in theory, here an improvement in the terms of trade is associated with increased pollution intensity of exports. The parallel results for the pollution intensity of imports are shown in Table 5, column (1). While the results for trade barriers and entrance into the WTO are similar to that of exports, the results for other variables are much weaker.

C. Composition effects and fragmentation

Moving beyond the simple model, we incorporate both ordinary and fragmented exports, as in the

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[29] GDP per capita is in constant 2000 US dollars.

[30] TRAINS has no Chinese tariff data for 1994-1995 or 2002. The simple average MFN tariff data for 1994-5 (with no AVE correction) was taken from Zhang et al. (1998), and for 2002 (with no AVE correction) was taken from the WTO (2006).

reduced form model in equation (13). This model suggests that changes in overall pollution intensity will be explained not only by the changing pollution intensity of ordinary exports, as in (5)′, but by growth in the share of fragmented exports and changes in that subsector's pollution intensity. The share of exports (imports) which are fragmented is proxied by the share of processing exports (imports) in total exports (imports). This variable is calculated directly from the trade data from China Customs; it includes both exports (imports) designated as processing and assembly, and those designated as processing with imported materials. We begin by treating the processing share as exogenous, and simply add the change in this share to equation (5)′.

The results of this estimation (column (2) of table 4) show weak support for the idea that increased fragmentation has reduced the pollution intensity of China's exports. An increase in the share of processing exports by a percentage point reduces the pollution intensity of China's exports by about 0.01%. The share of processing exports actually grew by about 6% during this time period, implying a larger impact than the small elasticity might suggest. However, in this specification, the estimate is not significant. The inclusion of the export processing share also strengthens the magnitude and significance of factor endowments and real GDP per capita in explaining the pollution intensity of exports over time. The parallel results for imports (table 5, column (2)) are even more striking. The impact of an increase in the lagged share of processing imports on the pollution intensity of China's imports is much larger and more significant (compare tables 4 and 5, column (2)). In addition, the inclusion of the lagged import processing share also dramatically strengthens the significance of all other explanatory variables (compare table 5, columns (1) and (2)).

However, the size of the fragmented sector is most likely endogenous. Clearly changes in trade frictions and factor endowments influence the size of the processing export share. Trade barriers on imports in highly fragmented sectors have fallen over this time period.[31] China's entrance into the WTO has also meant more favorable access for China's ordinary and fragmented exports in other WTO members' markets.

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[31] For example, the WTO (2006) reports that average tariffs on electronic and communications equipment imports fell with accession to the WTO. In April, 2003 China joined the WTO Information Technology Agreement, and 258 tariff lines at the HS 8-digit level became subject to zero tariffs. Import licenses and quotas on certain products have also been removed.

As discussed above, growth in foreign investment is predicted to raise the processing share of exports. Similarly, if export processing is more human-capital intensive than ordinary export processing, growth in the relative supply of human capital will raise the share of resources devoted to export processing.

To account for this endogeneity, we re-estimate equation (13)′, using instrumental variables. The instruments for processing export share include all other variables in the equation and the share of processing imports. Since by law, goods imported under the processing regime can only be used for production of processing exports, the share of processing imports should be a good predictor of the share of processing exports, while being uncorrelated with the dependent variable. The instrumented results (column (3)) now show much stronger evidence that growth in the share of fragmented exports leads to cleaner exports. The elasticity of pollution intensity with respect to processing export share is much larger, and is now highly significant. The role of factor endowments in strengthened by the IV estimation and growth in real GDP per capita now significantly reduces the pollution intensity of exports.

Table 5, column (3) shows the IV estimation for imports. In this case, the instruments include all other variables in the equation and the share of processing exports lagged two periods. The IV estimates are generally larger than those that ignored endogeneity, but otherwise simply reinforce the role of fragmentation found in column (2).

D. Composition effects, technique effects, and FDI

Thus far we have not distinguished investment by source nor labor by skill. Yet FDI plays a crucial role in fragmented trade. As argued above, an increase in FDI flows should reduce pollution intensity by increasing the share of processing exports and by increasing the critical value, z*. Domestic capital, in contrast, flows primarily to the import-competing and ordinary export sectors. Thus, an increase in domestically-sourced investment pulls factors out of the export-processing sector, reducing the critical value z*, and increasing the average pollution intensity of the export-processing sector.[32] Production shifts to the more highly polluting ordinary export sector. Therefore, we expect that an increase in domestic investment

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[32] The CC line in Figure 7 shifts up when labor is pulled out of the sector and wages rise.

raises the pollution intensity of China's exports.

An increase in the relative supply of human capital acts, in the model, like a decrease in the Chinese effective wage. A decrease in w shifts the CC line down in figure 7, allowing China to compete successfully in production of more human-capital-intensive intermediate inputs. Thus, an increase in Chinese human capital is predicted to reduce the pollution intensity of China's exports. An increase in unskilled labor, on the other hand, is predicted to have the opposite effect.

The last two columns of table 4 show evidence that is certainly suggestive of the important role that increased FDI and increased human capital play in making Chinese exports cleaner. In column (4) of table 4, we present results for the instrumented estimation of (13)′ again, but with investment split between domestically-sourced investment and FDI. FDI (% of GDP) is taken from the *World Development Indicators.*[33] Domestically-sourced investment (as a share of GDP) is calculated as the difference between gross capital formation and FDI. It is immediately evident that these two types of investment have opposite effects. As expected, increased FDI flows strongly reduce the pollution intensity of Chinese trade, while increased domestically-sourced investment does the opposite. Because the effects of FDI flows on the size of the fragmented sector are captured via the IV estimation, the coefficient on the FDI variable actually suggests evidence of cleaner exports due to a change in composition *within* the fragmented sector (an increase in z*). It may also suggest that foreign investors bring greener technologies than their local counterparts, implying an additional favorable technique effect. Parallel results for imports (table 5, column (4)) are much weaker and show no such role for FDI.

Because of the small sample size, we are unable to test for distinct roles of investment by source and labor by skill simultaneously. However, some evidence suggestive of the importance of both is shown in column (5) of table 4. In this final regression, we include the ratio of FDI to domestically-sourced investment as well as growth in the ratio of skilled to unskilled labor. The latter is proxied by the share of the population

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[33] These data closely parallel official Chinese data on utilized (or realized) FDI flows (% GDP) (see Annual FDI Statistics, www.fdi.gov.cn).

with at least senior secondary education, relative to the illiterate share.[34] The results in column (5) suggest that the pollution intensity of exports is strongly reduced by the relative growth of foreign investment and of skilled labor. This evidence is consistent with the notion that increased FDI flows expands the composition of fragmented exports to include cleaner intermediates and that more skill-intensive intermediates are cleaner. While the theory would suggest both these attributes should be true of imports as well, only the FDI results are borne out in table 5 (column (5)).[35]

VII. Global Engagement and the Environment

By all accounts, China's rapid economic growth over the past 20 years has been accompanied by severe environmental degradation. While much of this deterioration can be attributed to growth in domestic consumption, the extent to which China's environment has been sacrificed so that it can serve as "the world's factory" is an important economic and moral question. To begin to address this issue, this paper provides new evidence on trends in industrial pollution intensity, changes in the pollution intensity of Chinese trade, and the influence of foreign investment and production fragmentation on the pollution content of Chinese exports and imports. Contrary to the expectations of many commentators, we find that deeper global engagement has reduced the implicit environmental cost of Chinese income growth.

Using official Chinese environmental data on air and water pollution from SEPA, we find that industrial emissions of primary pollutants have slowed or fallen over the last decade while trade has grown. Relative to 1995 levels, real manufacturing trade increased almost 300% by 2005, while annual industrial emissions of COD, smoke, and dust declined by 56%, 46%, and 40%. Industrial emissions of SO_2 rose only after 1999, but were 17.5% higher than 1995 levels by 2005. As noted by Naughton (2007, p. 495), the abatement of waste from large factories has been a relatively positive part of China's environmental record and the stabilization of waste while output has grown sharply represents a significant achievement in its

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[34] Data on shares of population aged >6 years by educational attainment are from various issues of the China Statistical Yearbook. Data for the year 1995 are from Cao (2000), page 4.

[35] The results for the impact of the ratio of skilled to unskilled labor on the pollution intensity of imports appear to be highly sensitive to the lag chosen. More data are required to determine how illustrative they really are.

development.

Using emissions data compiled from *Chinese Environment Yearbooks*, we present new evidence on the pollution intensity of Chinese industrial production. Tracking changes in these pollution intensities over time reveals surprising trends. Across all four pollutants, we find that the pollution intensity of almost all sectors has fallen since 1995. This finding suggests that China has benefited from a positive "technique effect," as emissions per real dollar of output have fallen across a wide range of industries. Suggestively, a review of trends in Chinese trade patterns reveals that China's trade appears to be shifting toward relatively cleaner sectors over time. In particular, the share of exports accounted for by textiles and leather products has fallen while the share accounted for by office and computing, and communications equipment has grown dramatically. These growth sectors are characterized by low air and water pollution intensities and by high shares of processing trade, indicating the substantial presence of two-way trade in production "fragments."

Linking the industrial pollution intensities to detailed trade statistics from China Customs yields a weighted average pollution intensity for China's manufacturing exports (imports) for each year in the period 1995 to 2005. Contrary to popular expectations, which emphasize the migration of dirty industries to poor nations, we find that Chinese exports are less water pollution intensive, and generally less air pollution intensive, than Chinese imports would be if produced domestically. Moreover, both Chinese exports and imports are becoming cleaner over time. Holding the pollution intensity of production constant in a counterfactual experiment, we find that changes in the composition of trade over the decade account for some of the trend toward cleaner trade, although a substantial share of the decline remains attributed to changes in production techniques. Finally, we find that processing trade is cleaner than ordinary trade.

The weight of this evidence suggests that the increased concentration of Chinese trade in highly fragmented industries has led to composition and technique effects which are favorable toward China's environment. Drawing on Copeland and Taylor (1994), we present a simple model of production and trade that leads to a reduced form equation for the pollution intensity of Chinese trade. Explicitly incorporating a role for fragmented trade yields a set of key determinants of the pollution intensity of trade: Chinese domestic factor endowments, foreign investment, the terms of trade, trade frictions, per-capita real income, and the share of trade in fragmented sectors, where this share is also influenced by the other key determinants. In theory, increased FDI inflows not only increase the size of the fragmented sector, but also reduce its average pollution intensity.

Econometric evidence from instrumental variables estimation strongly supports the role of processing trade in explaining the drop in the pollution intensity of Chinese exports and imports over time. This suggests that there is indeed a favorable composition effect generated by the increased importance of fragmentation in Chinese trade. The evidence also suggests that, controlling for the size of processing exports, FDI inflows contribute to cleaner exports. This supports the idea that increased FDI may change the composition of the fragmented sector itself toward relatively cleaner intermediate goods and may also bring greener technology to the fragmented sector.

In the Five-Year Plan for 2006-2010, the Chinese authorities call for a reorientation of their economic growth model toward environmental sustainability. How China will achieve the dual goal of economic growth and reduced environmental degradation is far from clear. Trade and foreign investment has fueled much of China's trade boom and so it is natural to ask whether China's unique brand of global engagement needs to be radically altered to move its development path in the desired direction. The new data analyzed in this paper suggests that, at least provisionally, the answer to this question is "no." Industrial pollution intensity has already stabilized and, in many industries, has begun to decline. Looking specifically at the bundle of goods China trades with the world, we find that, contrary to what might have been expected, foreign investment and integration into global production networks has reduced the environmental cost of China's growth.

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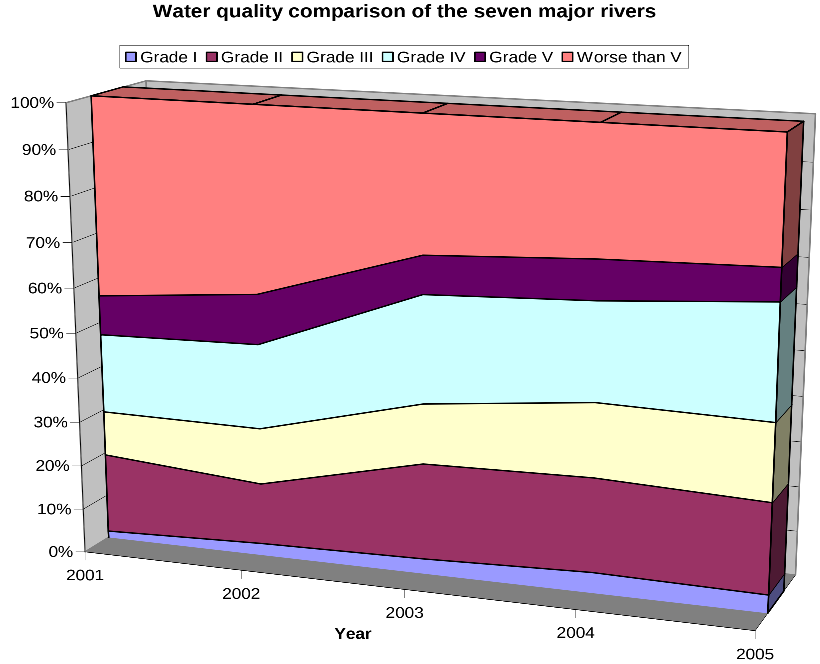
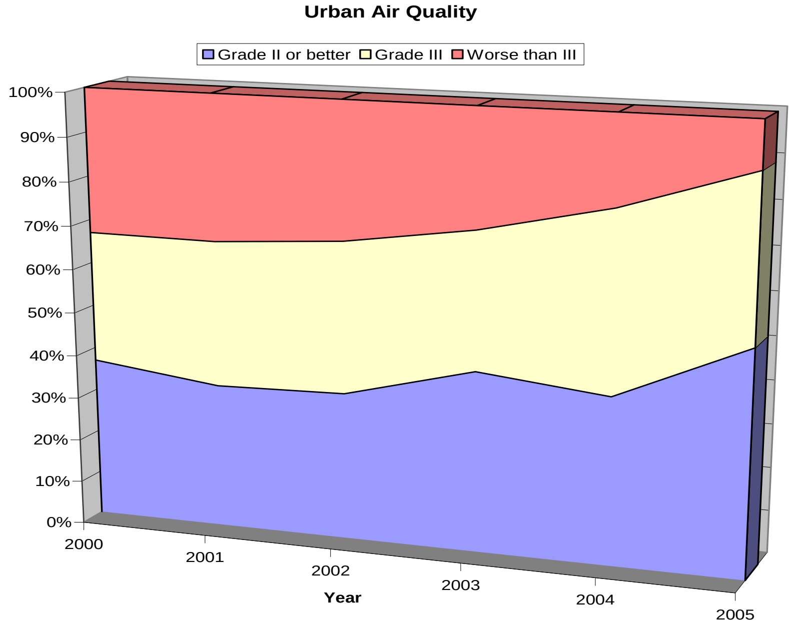
Figure 1



Data from SEPA, *Report on the State of the Environment*, various years. Downloaded from http://www.sepa.gov.cn/ghjh/hjzkgb. Comparable data for earlier years are unavailable.

Figure 2



Data from SEPA, *Report on the State of the Environment*, various years. Downloaded from http://www.sepa.gov.cn/ghjh/hjzkgb. Comparable data for earlier years are unavailable.

Figure 3. China's Trade and Industrial Emissions, 1995-2005

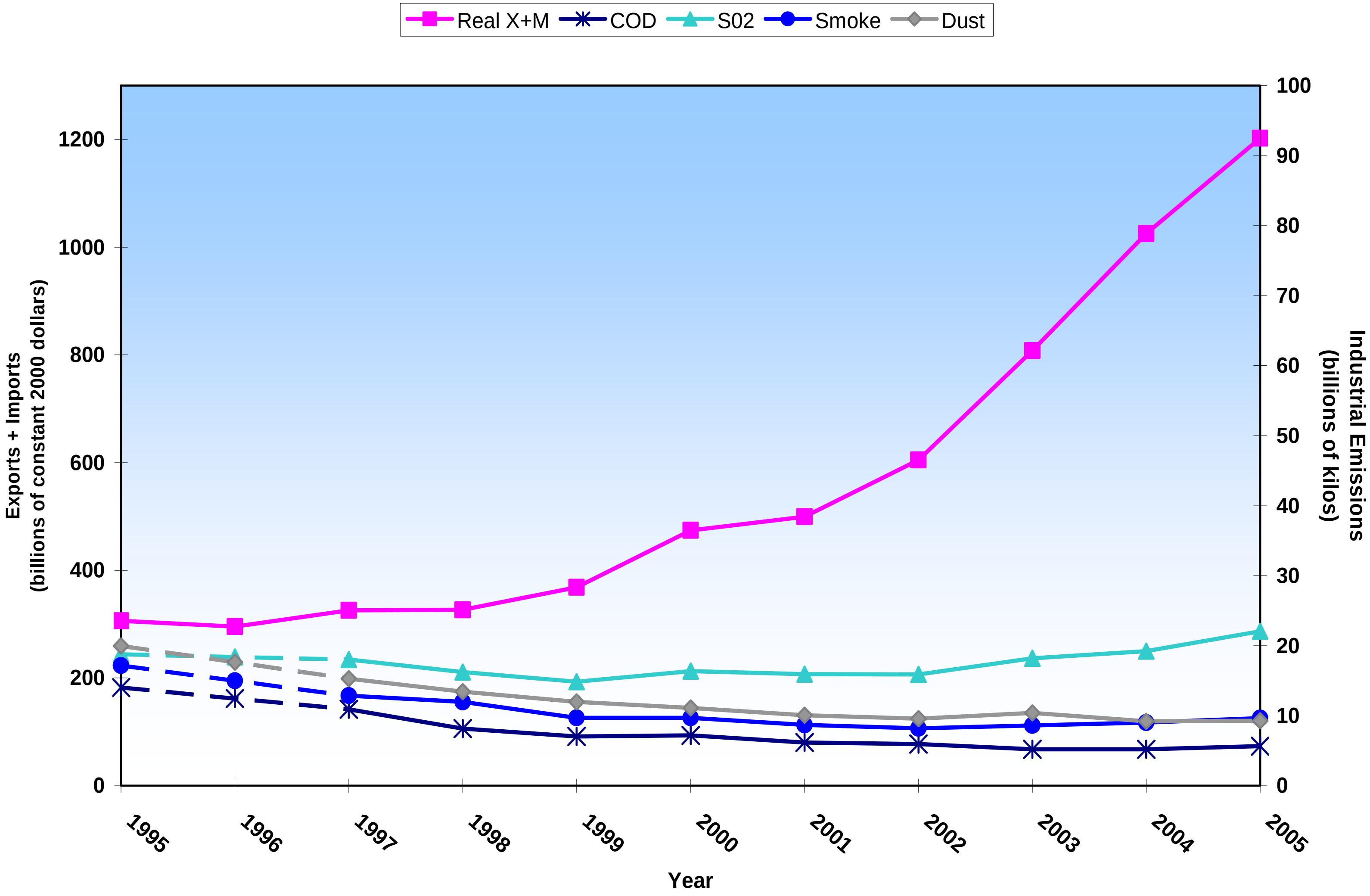


Figure 4. China's Trade and Industrial Emissions
(Index, 1995=100)

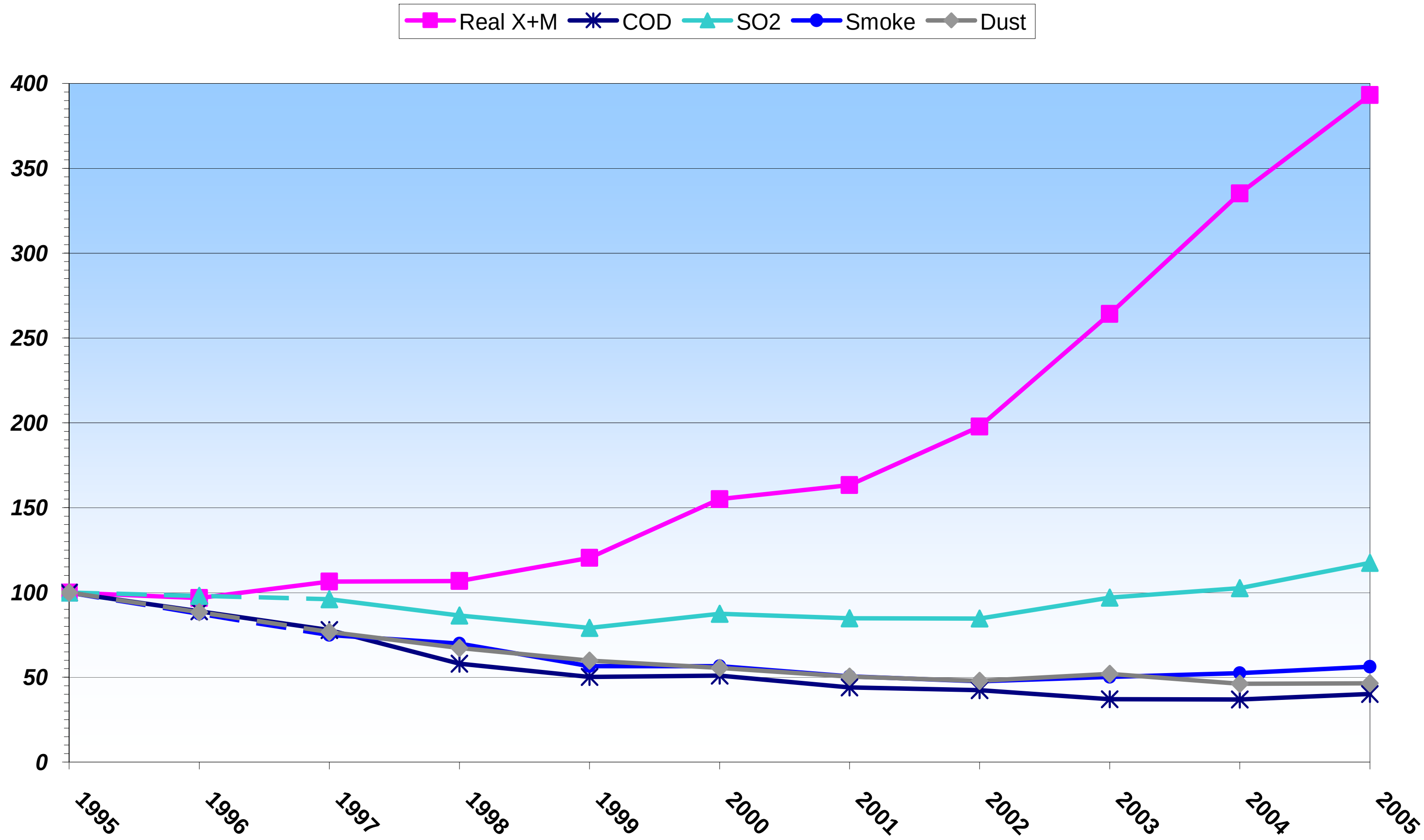
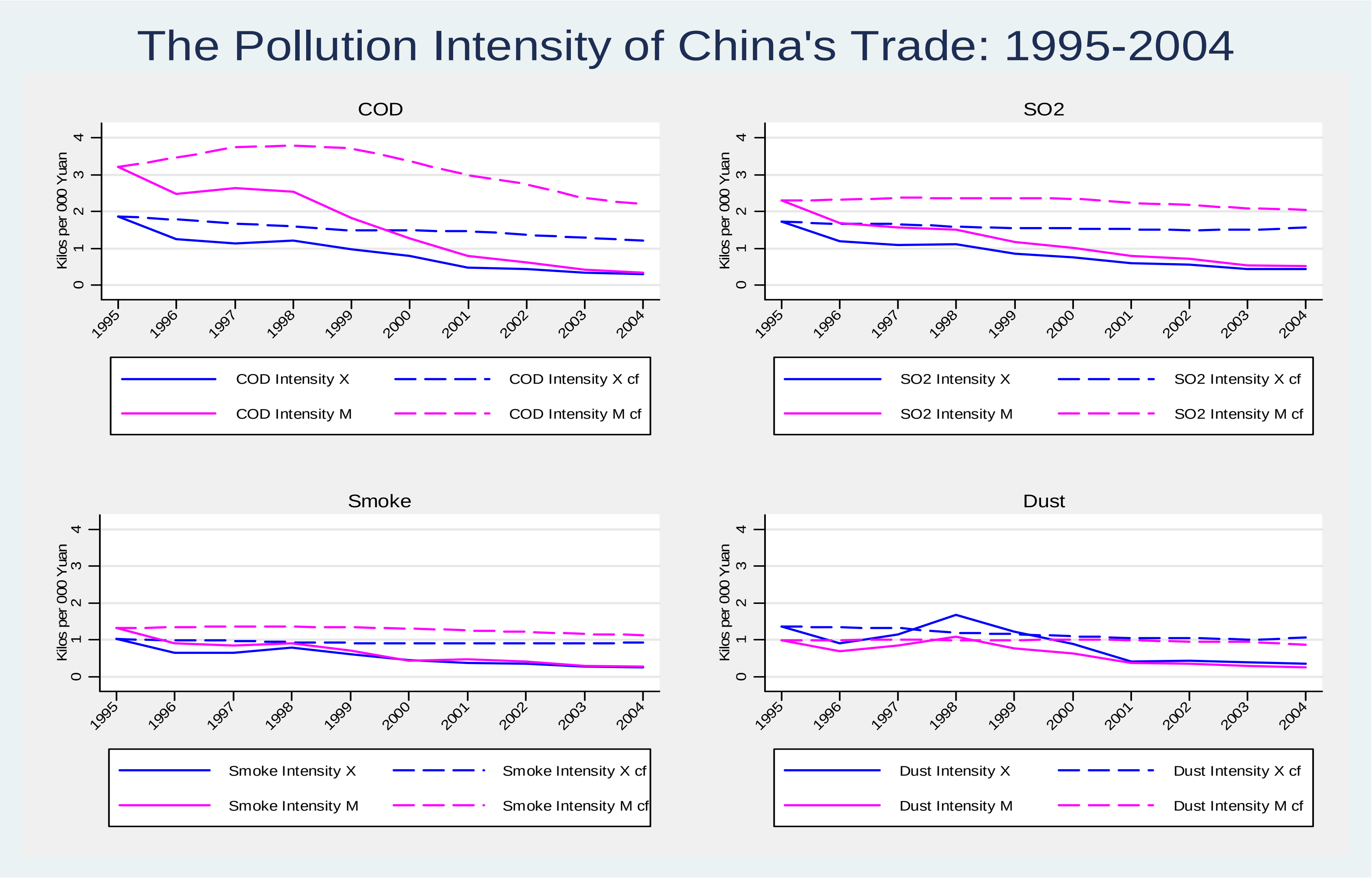
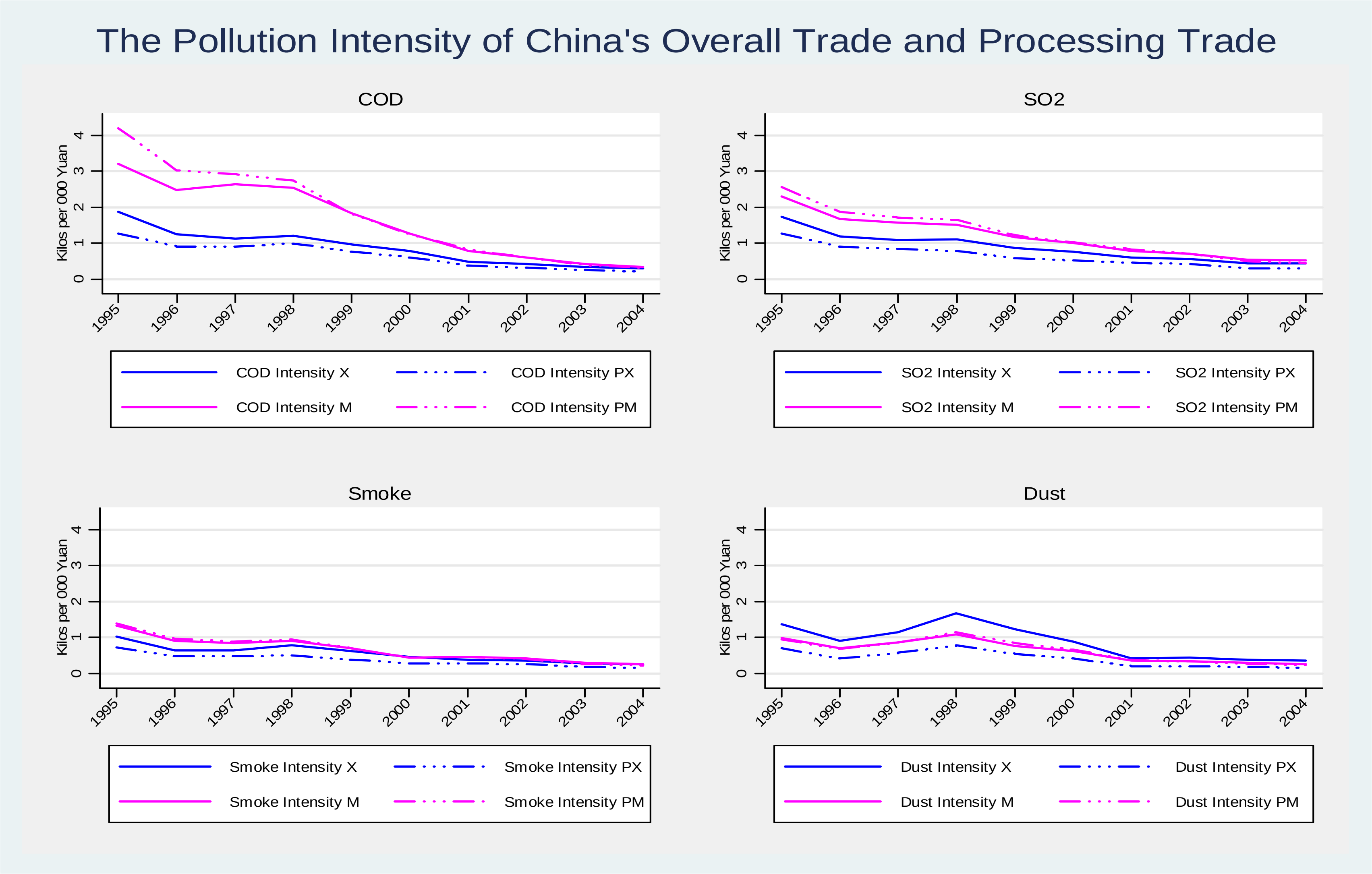


Figure 5.



Source: Data calculations by authors, as described in the text.

Figure 6:



Source: Data calculations by authors, as described in the text.

Figure 7: FDI Expands Range of Export Processing Activities Performed in China

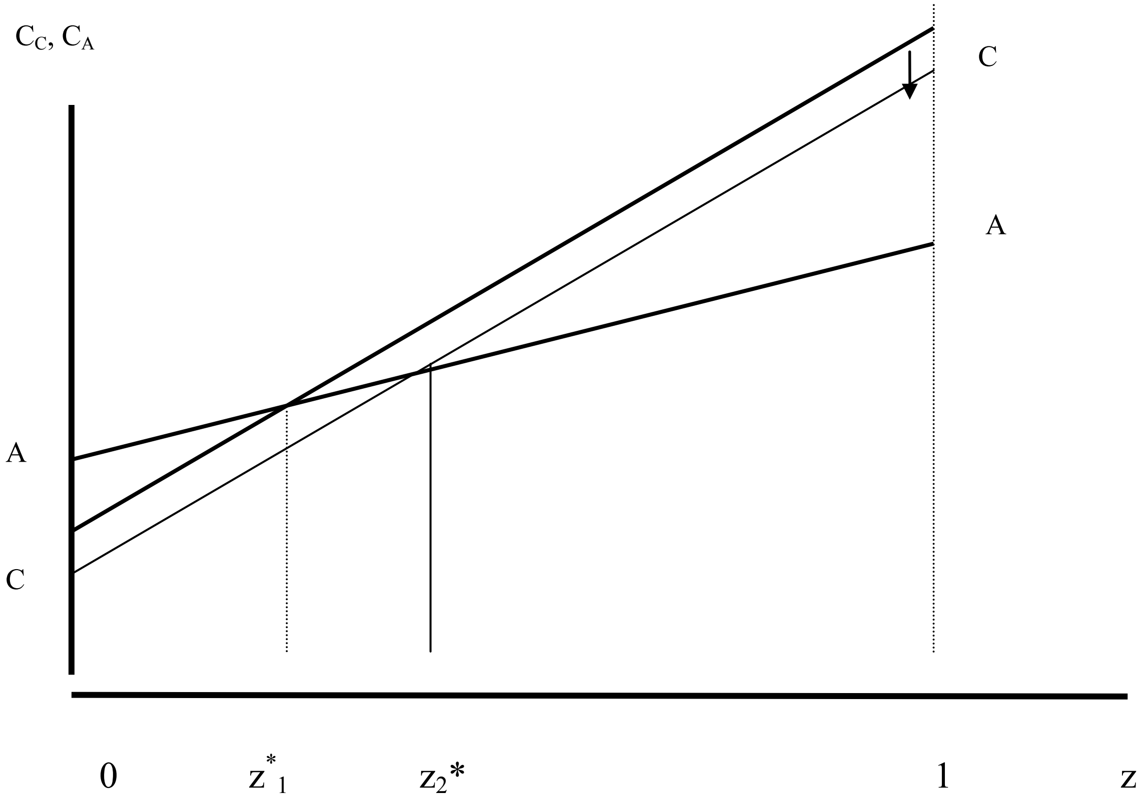


Table 1. The Composition of China's Trade, 1995 and 2004

ISIC Rev. 3 Two Digit Sector		China Mfg Exports				China Mfg Imports			
		Share of Total Mfg Exports (%)		Processing Exports as a Share of Mfg Exports (%)		Share of Total Mfg Imports (%)		Processing Imports as a Share of Mfg Imports (%)	
		1995	2004	1995	2004	1995	2004	1995	2004
15	Food Products and Beverages	5.5	2.6	24.4	31.0	4.9	2.4	45.2	26.2
16	Tobacco	0.7	0.0	26.6	2.9	0.3	0.0	0.3	0.3
17	Textiles	13.8	8.2	32.3	25.7	9.1	3.1	97.2	90.7
18	Wearing Apparel	14.2	8.6	54.4	31.0	0.8	0.3	96.5	73.0
19	Leather Shoes	7.3	4.1	72.7	47.0	1.9	0.8	98.6	85.9
20	Wood	1.5	1.0	14.8	19.4	1.0	0.5	44.4	59.9
21	Paper	0.6	0.4	42.3	59.8	2.5	1.7	66.1	38.2
22	Printing	0.1	0.1	79.5	54.3	0.0	0.0	55.0	35.2
23	Coke and Petroleum	1.3	1.5	26.2	24.4	2.2	2.6	9.1	2.7
24	Chemicals	6.8	4.8	21.0	25.3	15.8	14.3	53.3	33.3
25	Rubber and Plastics	2.7	2.7	71.7	62.7	1.8	1.7	83.0	56.1
26	Non-metallic minerals	2.3	1.7	14.7	17.2	0.8	0.7	40.1	48.5
27	Basic metals	5.2	4.1	56.1	27.5	8.8	8.4	52.3	40.1
28	Fabricated metals	3.4	3.5	36.9	25.5	1.8	1.3	43.2	37.7
29	Machinery	4.7	7.2	45.7	48.2	20.7	12.8	3.8	7.8
30	Office and Computing Machinery	3.5	15.1	94.7	95.8	2.4	6.2	66.8	50.3
31	Electrical Machinery	5.1	5.8	69.9	62.4	5.1	6.0	50.7	52.6
32	Communications Equipment	7.8	15.7	85.6	86.0	10.4	23.0	59.8	71.9
33	Medical, Precision and Optical Instruments	2.9	3.0	80.5	76.2	3.6	8.6	42.8	57.0
34	Motor vehicles	1.4	2.1	73.6	59.8	2.5	3.3	4.2	2.1
35	Transport equipment	1.5	1.7	59.6	53.3	2.5	1.4	7.8	4.5
36	Furniture and Other Mfg.	7.9	6.3	68.6	59.7	1.1	0.6	72.2	57.4

Table 2. Pollution Intensity of Chinese Industrial Output, 1995 and 2004

ISIC Rev. 3 Two Digit Sector		1995				2004			
		COD	SO2	Smoke	Dust	COD	SO2	Smoke	Dust
		(kilos per thousand yuan output, 1995 yuan)				*(kilos per thousand yuan output, 1995 yuan)*			
15	Food Products and Beverages	**11.47**	2.62	2.06	0.17	**1.59**	0.59	0.66	0.04
16	Tobacco	0.20	0.28	0.10	0.03	0.02	0.05	0.03	0.01
17	Textiles	1.05	1.48	0.81	0.03	0.73	0.70	0.27	0.03
18	Wearing Apparel	0.61	0.63	0.35	0.01	0.44	0.35	0.17	0.02
19	Leather Shoes	2.05	0.84	0.48	0.04	0.70	0.23	0.16	0.01
20	Wood	5.41	3.41	4.56	**2.59**	0.92	1.15	**1.38**	**0.58**
21	Paper	**67.36**	**6.89**	**4.66**	0.61	**6.95**	**1.86**	1.08	0.07
22	Printing	0.18	0.64	0.32	0.00	0.08	0.09	0.07	0.00
23	Coke and Petroleum	0.79	2.85	1.67	1.15	0.08	0.85	0.58	0.19
24	Chemicals	3.19	4.17	2.29	0.58	0.67	1.13	0.54	0.16
25	Rubber and Plastics	0.17	1.08	0.46	0.05	0.10	0.26	0.11	0.05
26	Non-metallic minerals	0.35	**10.52**	**6.46**	**39.45**	0.14	**4.26**	**3.24**	**14.07**
27	Basic metals	0.81	5.33	2.10	**4.33**	0.12	1.26	0.50	**0.90**
28	Fabricated metals	0.12	1.47	0.74	0.18	0.08	0.32	0.14	0.10
29	Machinery	0.12	0.89	0.69	0.11	0.05	0.18	0.12	0.08
30	Office and Computing Machinery	0.08	0.34	0.22	0.01	0.03	0.03	0.03	0.01
31	Electrical Machinery	0.14	0.84	0.50	1.23	0.02	0.16	0.12	0.41
32	Communications Equipment	0.08	0.35	0.23	0.01	0.03	0.03	0.03	0.01
33	Medical, Precision and Optical Instrun	0.12	0.33	0.16	0.01	0.05	0.08	0.02	0.00
34	Motor vehicles	0.12	0.45	0.38	0.10	0.06	0.06	0.07	0.06
35	Transport equipment	0.12	0.43	0.37	0.10	0.06	0.06	0.07	0.06
36	Furniture and Other Mfg.	0.37	0.55	0.50	0.95	0.12	0.28	0.19	0.34
40	Electricity, Gas, Steam and Hot Water Supply	1.48	**93.22**	**57.71**	0.47	0.25	**19.93**	**6.98**	0.17
41	Collection, Purification, and Distribution of Water	**12.33**	2.79	1.67	0.45	**2.08**	0.92	0.34	0.00

Table 3. Trends in Chinese Trade, Investment and Growth

Year	Net Barter TOT	Simple Average Tariff	Gross Capital Formation	FDI/GDP	Labor Force Growth	GDI/GDP	Processing Exports (% of Total Exports)	Processing Imports (% of Total Imports)	Growth of Real GDP p.c.
1995	101.9	35.9	39.3	4.9	1.1	34.4	49.5	44.2	9.26
1996	105.9	22.0	37.7	4.7	1.2	33.1	55.8	44.9	8.48
1997	110.2	16.7	36.0	4.6	1.1	31.4	54.5	49.3	7.87
1998	110.6	16.6	35.0	4.3	1.0	30.7	56.8	48.9	6.55
1999	104.1	16.3	34.2	3.6	1.1	30.7	56.3	44.0	6.38
2000	100.0	16.2	32.8	3.2	1.0	29.6	54.7	40.8	7.36
2001	100.9	15.2	34.2	3.3	1.0	30.8	54.4	38.3	7.25
2002	100.5	12.2	35.2	3.4	0.8	31.8	55.3	41.5	8.04
2003	97.3	10.5	37.8	3.3	0.9	34.6	55.4	39.7	8.91
2004	91.8	9.6	38.7	2.8	1.1	35.8	55.6	39.6	9.02

Notes: All variables except the trade variables are from the World Bank *World Development Indicators,* 2007. The trade data are from China Customs. See text for definitions of variables.

Table 4. The Change in the Pollution Intensity of China’s Exports[1]

	(1) Equ. (5)’		(2) Equ. (13)		(3) Equ. (13) IV		(4) Equ. (13) IV		(5) Equ. (13)IV	
Variables in log difference unless otherwise noted.	**Coeff.**	**t-stat**[4]	**Coeff.**	**t-stat**[4]	**Coeff.**	**t-stat**[4]	**Coeff.**	**t-stat**[4]	**Coeff.**	**t-stat**[4]
Gross Capital Formation[2]	0.04*	2.03	0.05*	2.24	0.12**	2.68				
Domestic Investment[2]							0.12**	4.34		
FDI[2]							-0.52**	-3.12		
Ratio of FDI to Dom. Inv.[2]									-0.11**	-3.27
Ratio of Skilled to Unskilled Labor[3]									-0.02**	-3.90
Labor Force	-0.32	-1.61	-0.35†	-1.73	-0.54†	-1.75	0.29	1.13		
Real GDP p.c.	-0.01	-0.30	-0.04	-0.76	-0.18†	-1.80	-0.34**	-3.52	-0.08	-1.33
Terms of Trade[3]	0.04**	5.08	0.04**	4.94	0.04**	3.31	0.12**	5.12	0.09**	6.00
Average Tariff	1.37**	5.05	1.23**	3.85	0.51	0.84	0.73**	2.40	1.24**	4.65
WTO Dummy	-0.42**	-6.11	-0.42**	-5.92	-0.39**	-3.70	-0.83**	-5.91	-0.87**	-7.60
Processing Exports Share[3]			-0.01	-0.94	-0.08*	-2.15	-0.02*	-2.00	-0.03*	-2.25
Constant	-0.91*	-2.02	-1.11*	-2.25	-2.25*	-2.58	0.75	1.09	2.18*	2.67
Obs.	36		36		36		36		36	
Weighted Adj. R^{2} [4]	0.65		0.65		0.36		0.74		0.74	
Weighted F-statistic [4]	11.71**		10.10**		12.26**		13.35**		15.73**	

Notes: **, * and † indicate statistical significance at the 1%, 5% and 10% levels, respectively.

[1] Dependent variable is log difference of pollution intensity of exports. All regressions are GLS with panel-specific weights to correct for pollutant-specific heteroskedasticity.

[2] Expressed as share of GDP.

[3] Expressed as difference between value in period t and period t-1.

[4] Eviews output gives weighted adjusted R^{2} and F-statistics, where the weights adjust for the cross-section weights. Eviews also gives t-statistics rather than z-statistics.

Table 5. The Change in the Pollution Intensity of China's Imports[1]

	(1)		(2)		(3)		(4)		(5)	
	Equ. (5)'		**Equ. (13)**		**Equ. (13) IV**		**Equ. (13) IV**		**Equ. (13)IV**	
Variables in log difference unless otherwise noted.	**Coeff.**	**t-stat[4]**	**Coeff.**	**t-stat[4]**	**Coeff.**	**t-stat[4]**	**Coeff.**	**t-stat[4]**	**Coeff.**	**t-stat[4]**
Gross Capital Formation[2]	0.03	1.19	0.13**	3.34	0.16**	2.69				
Domestic Investment[2]							***0.14****	***3.32***		
FDI[2]							***0.43***	***1.01***		
Ratio of FDI to Dom. Inv. (lagged)[2]									***-0.21****	***-2.37***
Ratio of Skilled to Unskilled Labor (lagged)[3]									***0.13****	***3.04***
Labor Force	-0.01	-0.06	-0.26	-1.13	-0.35	-1.32	-0.66	-1.08		
Real GDP p.c.	0.01	0.16	-0.15*	-2.19	-0.21*	-2.02	-0.08	-0.67	-0.93*	-2.73
Terms of Trade[3]	0.05**	4.42	0.06**	5.79	0.06**	5.12	0.03	0.63	0.05**	3.71
Average Tariff	1.22**	3.62	1.19**	4.18	1.19**	4.05	1.38**	3.59	-5.09*	-2.58
WTO Dummy	-0.32**	-3.71	-0.40**	-5.00	-0.43**	-4.40	-0.24	-0.98	-2.62**	-3.32
Processing Imports Share (lagged)[3]			***-0.04****	***-3.20***	***-0.06****	***-2.38***	***-0.06****	***-2.28***	***-0.03****	***-2.13***
Constant	-1.03	-1.85	-2.99**	-3.80	-3.63**	-3.01	-4.66**	-1.90	8.66*	2.61
Obs.	36		36		36		36		32	
Weighted Adj. R^2 [4]	0.39		0.52		0.49		0.51		0.48	
Weighted F-statistic [4]	4.77**		6.32**		4.76**		5.54**		5.11**	

Notes: **, * and † indicate statistical significance at the 1%, 5% and 10% levels, respectively.

[1] Dependent variable is log difference of pollution intensity of imports. All regressions are GLS with panel-specific weights to correct for pollutant-specific heteroskedasticity.

[2] Expressed as share of GDP.

[3] Expressed as difference between value in period t and period t-1.

[4] Eviews output gives weighted adjusted R^2 and F-statistics, where the weights adjust for the cross-section weights. Eviews also gives t-statistics rather than z-statistics.

Appendix

Construction of the pollution intensities of Chinese manufacturing industries, 1995-2004

Data on emissions of COD, SO_2, smoke and dust, as well as the current value of output of the sampled enterprises at the industry level, were compiled by the authors from the *Chinese Environmental Yearbooks* (Chinese editions) and the *China Statistical Yearbook on Environment* (dual language, 2000, 2005 and 2006). Emissions data are originally in tons and output in 1000 current yuan. They are available by the 2-digit "divisions" in the Chinese industrial classification system for the industrial sector, which includes Mining (6 divisions), Manufacturing (30 divisions) and Distribution of Electricity, Water and Gas (3 divisions). Pollution intensities were calculated as emissions (in kilos) per thousand real yuan (1995 yuan). Output was deflated using the manufacturing producer price index (*China Statistical Yearbook, various issues).* These pollution intensities are shown for Manufacturing and for the Distribution of Electricity, Water and Gas, by division (GB/T 4754-2002), in table A.1.

Change in Chinese Industrial Classifications

Prior to 2001 Chinese industrial data were classified using GB/T 4754-1994. From 2001 onwards industrial data are classified using GB/T 4754-2002. In both classifications, manufacturing has 30 2-digit "divisions." Using the official Chinese concordance, we compared the two classifications and found only two changes in manufacturing divisions.[1] First, the 1994 division 39 (weapons and ammunition mfg.) became part of 2002 division 36 (special equipment mfg.).[2] We address this change under aggregation issues below. Second, the 2002 division 43 ("waste recycling") was added. This division was not part of manufacturing in the previous period. Therefore, we dropped it from the analysis.

Aggregation and Missing Data

In the published emissions and output data from 1995-2000, several divisions are aggregated together. Divisions 13-16 are grouped as "Food, Beverages and Tobacco," divisions 35-41 are grouped as

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[1] The 4-digit "classes" within each 2-digit division remained essentially unchanged. There were fewer classes in total in the 2002 classification, largely due to merges of classes within the same division.

[2] The remaining 2002 division codes were renumbered accordingly. Thus, 1994 division 40 corresponds to 2002 division 39, 1994 division 41 corresponds to 2002 division 40, etc.

"Machine, Electric Machinery & Electronic Equipment Mfg.," and divisions 44-46 are grouped as "Production and Supply of Electric Power, Gas, and Water. To disaggregate these grouped data, we first created corresponding groups for the years 2001-2004 by summing the appropriate division data. For each group, we calculated the average share of emissions of each pollutant attributable to each division within the group. We then applied these shares to the recorded group data in the earlier period. The group's annual emissions data from 1995-2000 for each pollutant was multiplied by the corresponding average share to derive the missing annual emissions data for each division within that group. We followed a similar procedure to derive the missing output data for each division within each group.

For example, during 2001-2004, Food Production (14) was responsible on average, for about 16 % of annual COD emissions and about 17% of annual output of "Food, Beverages and Tobacco." Therefore, for each year during 1995-2000, 16% of the recorded COD emissions and 17% of the recorded output for that group were allocated to Food Production.

This method assumes that the 2001-2004 relative trends in emissions of each pollutant and in output across divisions within a group apply during the earlier period. This is certainly plausible. However, it could mask any radical changes in technique or in composition within a group which took place in a single year.

Emissions and output data for 5 divisions during the 1995-2000 period are missing: Clothes, Shoes and Hat Manufacture (18), Timber Processing, etc. (20), Furniture Manufacturing (21), Cultural, Educational and Sports Articles (24), and Craftwork and Other (42). To fill in the missing data for the first three, we paired each missing division with a related division for which complete data were available: (18) with (17) textiles; (20) with (22) papermaking and paper products; (21) with (22). For each pair, we calculated the average ratio of emissions of each pollutant for the missing division relative to the complete division during 2001-2004. These ratios were then applied to the recorded data for the complete division in the earlier period For each year of 1995-2000 we multiplied the complete division's data by these average emissions ratios, to derive the annual emissions data for the missing division in that pair. We then followed a similar procedure to derive the output data for the missing division.

For example, during 2001-2004 we found that the ratio of COD emissions for Clothes (18) relative to Textiles (17) averaged about 3.3%, while the ratio of SO_2 emissions averaged about 4.1%. Therefore, for each year during 1995-2000, we assigned values for division (18) COD and SO_2 emissions that were 3.3% and 4.1%, respectively, of the recorded data for division (17).

We were unable to find a related division to pair with (24) or (42). Therefore, these data are missing during 1995-2000.[3] These missing data essentially impact our estimates of the pollution intensity of ISIC 36 (Furniture and other manufacturing, not elsewhere specified). Division (24) maps almost exclusively to ISIC 36. The classes in division (42) map to several 2-digit ISIC categories, but mostly to ISIC 36. These two divisions accounted for 76% (47% and 29%, respectively) of ISIC 36 exports in 1995, but declined in importance over the period. By 2000, they accounted for only 57% (45% and 12%, respectively), while furniture's share had roughly doubled (11% to 19%). Thus, while the pollution intensity of exports of ISIC 36 in our analysis during 1995-2000 is based nearly exclusively on the pollution intensity of furniture production, any bias this may introduce diminishes over these five years[4]

Emissions from township and village level enterprises (TVIEs)

Emissions data prior to 1998 were recorded only for industrial enterprises at the "county level and above." After the *"Investigation on Sources of Township Industrial Pollution"* (1997), it was found that township and village industrial enterprises (TVIEs) were accounting for a significant and growing percentage of emissions. Therefore, the emissions data included these enterprises from 1998 onwards. Because TVIE emissions data are unavailable at the sectoral level, the yearly industrial pollution intensities in 1995-1997 do not include TVIEs. Thus, the values for 1995 in table A1 and in table 2 are likely to be understated.

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[3] These two divisions together account for only about 6% of manufacturing exports in 1995, and about 4% in 2000.

[4] The data for 2001-2004 in table A1 suggest that this omission might bias the water pollution intensity of ISIC 36 upwards, but its impact on air pollution intensity is unclear.

Table A1. Pollution Intensity of Chinese Industrial Output, 1995 and 2004 by Industry (Chinese classification GB/T 4754-2002)

Division	1995				2004			
	COD	SO2	Smoke	Dust	COD	SO2	Smoke	Dust
	(kilos per thousand yuan output, 1995 constant yuan)				*(kilos per thousand yuan output, 1995 constant yuan)*			
13 Agricultural and Sideline Foods Processing	13.30	2.43	2.29	0.23	1.87	0.55	0.77	0.06
14 Food Production	7.65	2.47	1.09	0.08	1.10	0.62	0.38	0.02
15 Beverage Production	9.57	3.38	2.40	0.07	1.26	0.72	0.61	0.02
16 Tobacco Products Processing	0.20	0.28	0.10	0.03	0.02	0.05	0.03	0.01
17 Textile Industry	1.07	1.53	0.84	0.03	0.74	0.72	0.28	0.03
18 Clothes, Shoes and Hat Manufacture	0.31	0.56	0.31	0.01	0.33	0.29	0.14	0.02
19 Leather, Furs, Down and Related Products	2.57	0.74	0.47	0.03	0.87	0.22	0.17	0.00
20 Timber Processing, Bamboo, Cane, Palm Fiber and Straw Products	6.08	3.83	5.12	2.91	1.02	1.28	1.55	0.64
21 Furniture Manufacturing	0.94	1.07	1.25	0.54	0.14	0.22	0.16	0.01
22 Papermaking and Paper Products	70.02	7.08	4.80	0.63	7.22	1.90	1.11	0.07
23 Printing and Record Medium Reproduction	0.18	0.64	0.32	0.00	0.08	0.09	0.07	0.00
24 Cultural, Educational and Sports Articles Production					0.09	0.31	0.18	0.29
25 Petroleum Processing, Coking and Nuclear Fuel Processing	0.79	2.85	1.67	1.15	0.08	0.85	0.58	0.19
26 Raw Chemical Material & Chemical Products	3.07	5.08	2.77	0.78	0.65	1.34	0.66	0.22
27 Medical and Pharmaceutical Products	3.51	1.71	0.99	0.02	0.72	0.45	0.22	0.01
28 Chemical Fiber	3.42	2.34	1.33	0.17	0.69	0.89	0.28	0.02
29 Rubber Products	0.33	1.77	0.82	0.15	0.08	0.41	0.18	0.00
30 Plastic Products	0.10	0.79	0.31	0.01	0.11	0.20	0.08	0.07
31 Nonmetal Mineral Products	0.36	10.73	6.59	40.26	0.14	4.33	3.29	14.29
32 Smelting & Pressing of Ferrous Metals	1.05	4.63	2.25	5.56	0.14	0.98	0.47	1.05
33 Smelting & Pressing of Non-ferrous Metals	0.24	8.01	1.87	1.49	0.09	2.20	0.63	0.59
34 Metal Products	0.11	1.02	0.65	0.07	0.08	0.17	0.09	0.05
35 Ordinary Machinery Manufacturing	0.11	0.97	0.78	0.13	0.06	0.22	0.14	0.09
36 Special Equipment Manufacturing	0.21	0.98	0.72	0.10	0.07	0.17	0.08	0.03
37 Transport Equipment Manufacturing	0.12	0.43	0.37	0.10	0.06	0.06	0.07	0.06
39 Electric Machines and Apparatuses Manufacturing	0.13	0.54	0.31	0.02	0.02	0.04	0.03	0.02
40 Communications Equipment, Computer and Other Electronic Equipment Manufacturing	0.08	0.35	0.23	0.01	0.03	0.03	0.03	0.01
41 Instruments, Meters, Cultural and Office Machinery Manufacture	0.11	0.24	0.08	0.00	0.05	0.07	0.01	0.00
42 Craftwork and Other Manufactures					0.09	0.13	0.08	0.09
43 Waste Resources and Old Material Recycling and Processing					0.03	0.08	0.05	0.02
44 Electricity and Heating Production and Supply	1.45	95.80	59.25	0.26	0.24	20.44	7.16	0.16
45 Fuel Gas Production and Supply	2.47	9.69	7.77	7.20	0.75	1.84	0.80	0.52
46 Water Production and Supply	12.33	2.79	1.67	0.45	2.08	0.92	0.34	0.00