Chinese Growth and Atmospheric Pollution:
An empirical assessment of challenges and opportunities

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April, 2004
(Preliminary Version)

ABSTRACT

This paper uses a dynamic CGE model, calibrated to new and detailed Chinese emissions data, to assess two important questions. What can we reasonably expect Chinese emissions trends to look like over the next two decades? Secondly, what would be the appropriate policy interventions to flatten Chinese emissions trajectories and reduce the risk of local, regional, and even global adversity? This research is original in its direct use of the new industrial sector-level emissions and energy using data from China to estimate the energy-specific emission effluent rate and its detailed treatment of policies taking account of the three main determinants of pollution intensity: growth, output composition, and technological change. Our results indicate that trade-offs between these three, under a facilitating policy environment, might allow sustained increases in Chinese living standards without significantly adverse environmental externalities, domestically or internationally. The results indicate that, without further effective emission control measures, China's economic growth over the next two decades will contribute significantly to SO_2 emission problems. However, detailed examination of the structural and technological components of pollution shows that efficient pollution mitigation can be realized by focused abatement activities, cleaner production, and advances in cleaner fuel products and their use technologies.

[†] Paper presented at the Seventh Annual Conference on Global Economic Analysis: Trade, Poverty, and the Environment, June 17 - 19, The World Bank, Washington, D.C All opinions expressed here are those of the authors and should not be attributed to their affiliated institutions. Contacts: Jie.He@u-clermont1.fr and dwrh@are.berkeley.edu

1. Introduction

China's growth has set new standards for a dynamic economy, in Asia or anywhere else. The environmental implications of this growth are already being keenly felt locally and in the longer term are likely to be global. Atmospheric pollution within and emanating from China is already the subject of intensive research and policy debate. Although this economy is redefining our understanding of the process of industrialization in many ways, even technological leapfrogging cannot be expected to solve all pollution problems of an economy that still has to pass through the main stages of heavy industrial growth. Table 1 suggests the primary forces that will be at work during China's longer term economic transition. In terms of steel production per capita, China is at the early stages of industrialization while Japan and the United States can be seen as post-industrial societies, China must still go "over the mountain" of industrial intensity, represented here by Korea. Even if China finds a pass around the peak scaled by Korea, its industrial intensity must obviously increase by multiples, with dramatic increases for energy use and pollution levels of the kind already being experienced since this data was sampled. The second column of Table 1 has even more serious implications, making it clear that maturing to a service intensive economy provides no respite for energy demand. On the contrary, energy use in the most service-intensive economy (US) is nearly four times that of the most industry intensive (Korea).

TABLE 1. PER CAPITA STEEL AND ENERGY

	Annual Kilograms Per Capita	
Country	**2001 Steel Production**	**2000 Oil Consumption***
China	132	905
Korea	809	2071
Japan	575	4136
France	390	4366
United States	373	8141

*BTU equivalent kg from all energy sources

Much of the North-South energy/environment debate has been focused on the dilemma suggest in Table 1. In their drive to realize precisely the same material aspirations already enjoyed by OECD countries, the populous developing countries present new challenges for themselves and the global environment. Clearly, China's aspiration to fulfill its enormous economic potential will have implications for everyone. In contention over this issue, some aspects of the policy dialogue seem to ask "How big a house can China have?" Given the disparity of North-South living standards, this question is hypocritical at best. Having said that, however, it is certainly reasonable to ask how China's house can be built in a way that raises the property values for the entire neighborhood. In this paper, we address this question by trying to elucidate linkages between alternative growth strategies and policies intended to flatten the pollution trajectories arising from China's recent industrial expansion. [1]

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[1] WDI, 2003.

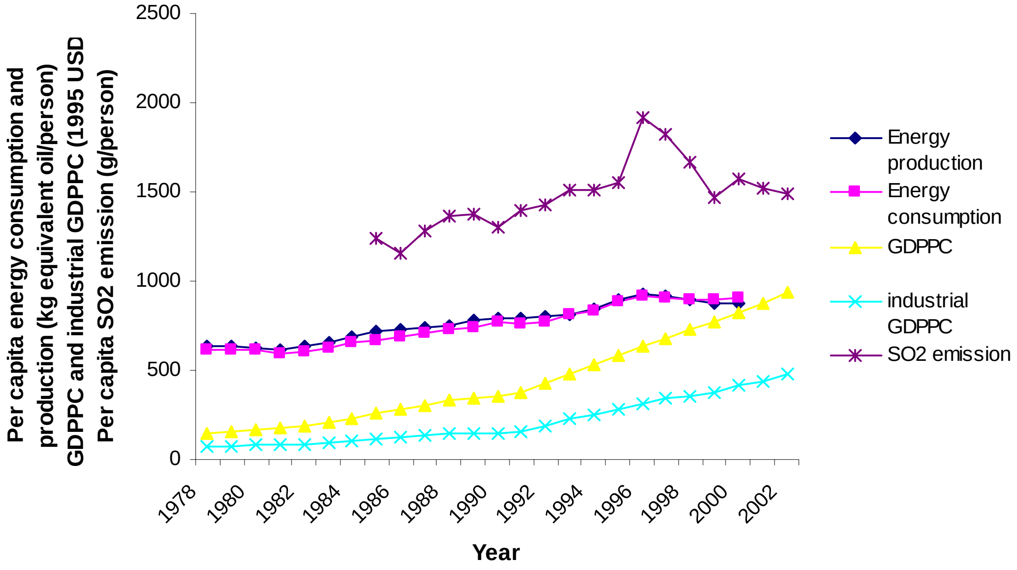
This paper uses a dynamic CGE model, in which emission is considered as a joint-product, directly linked to energy consumption in production activities. The model also incorporates substitution between energy sources of differing pollution-intensity. Given the importance of trade in the wake of China's WTO accession, we also incorporate a positive growth externality from trade in the model specification. The model is then calibrated to new and detailed Chinese emissions data, to evaluate two important questions. In light of dramatic industrialization and economic growth, increased openness, and China's natural resource (especially energy) endowments, what can we reasonably expect emissions trends to look like over the next two decades? Secondly, what would be the appropriate policy interventions to flatten Chinese emissions trajectories and reduce the risk of local, regional, and even global environmental adversity? This research makes original contributions to our empirical understanding of China's environmental conditions, how policies can affect them, and how researchers can better understand these effects. In this analysis, we detailed analytical and empirical attention to all three of the main determinants of pollution: growth, sectoral output composition, and technological change.

The organization of the paper is as follows: Section 2 provides a brief overview of China's economic growth, energy use, and pollution situation since 1978. Section 3 explains our model specification. After a concise introduction to policy scenarios in section 4, we will give detailed discussion on simulation results in Section 5. Finally, concluding remarks and discussion of extensions of this work are given in Section 6.

2. Trends in Chinese Growth, Energy Use, and Pollution

Last twenty-five year of economic reform has brought to China unprecedented growth and modernization., Like many of the other countries at similar stages of development, however China's industrialization has been accompanied by obvious environmental deterioration. Figure 1 shows the increasing trends in Chinese economic growth, energy production and consumption and SO_2 emission during the last 25 years. With an average GDP growth rate of 9% and 9.3% for industrial GDP, per capita GDP in China has increased by more than six fold in the last two decades. Energy production and consumption and SO_2 emission seemed to grow at relatively slower rate. It should be noted that these trends actually reflect improvements in energy efficiency per unit of output, averting proportional pollution growth which would have been much more serious. The close historic link between energy production and consumption trends reveals past energy self-sufficiency, but this situation has changed rapidly since 1998. Today China has become the world's second largest importer of energy fuels, and the implications of its growth and energy energy demand now encompass global petroleum markets.

Figure 1. Economic growth, energy consumption and SO_2 emission situation (Per capita level)



Data source: WDI (2003), China Statistic Yearbook and China's Environment Statistic Yearbook

Figure 2 gives more detailed information on China's energy structure on both production and consumption aspects. Given China's relatively rich endowment of low cost coal, especially comparing to that of crude oil and natural gas, over 70% of her energy production was fueled by the domestic coal sector. At the same time, domestic crude oil production remained steady at about 200 MCTE each year. Though hydro-electricity production has grown steadily during the economic reform period, its share in total energy production has remained below 10%. Historically, natural gas production played actually a negligible role in the total energy supply.

Analogously, China's energy consumption structure reveals the dominance of coal. Since 1997, however, patterns of consumption diversification are emerging, undermining the dominance of coal in favor of crude oil and hydro-electricity. Today, however, coal remains the most important energy source fueling China's economic growth.

Energy demand diversification has unavoidably strengthened China's dependence on imported crude oil. Given the country's limited proven domestic reserves, and despite large investments to expand oil production capacity, domestic supply of crude oil is unlikely to increase in proportion to aggregate growth and indeed may be more likely to decline. The three main oil production zones, Daqing, Shengli and Laiohe, are considered to "be nearing depletion and can sustain their current level of production only with additional and sound investments".[2] For example, output from China's largest oil field in Daqing, decreased by 1.7 mm tons last year.[3] At the same time, the domestic oil consumption has grown steadily since 1980s and recently accelerated with rapid increases in urban automobile ownership.[4] As shown in Figure 3, the relatively stable production quantity seemed to lag behind the consumption growth since the second half of the 1990s. The gap between production and consumption was covered by the increases in net crude oil import, combining the effects of decreasing exports and fast growing imports. According to the International Energy Agency (IEA) and the Chinese government, in

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[2] Troush, 1999.

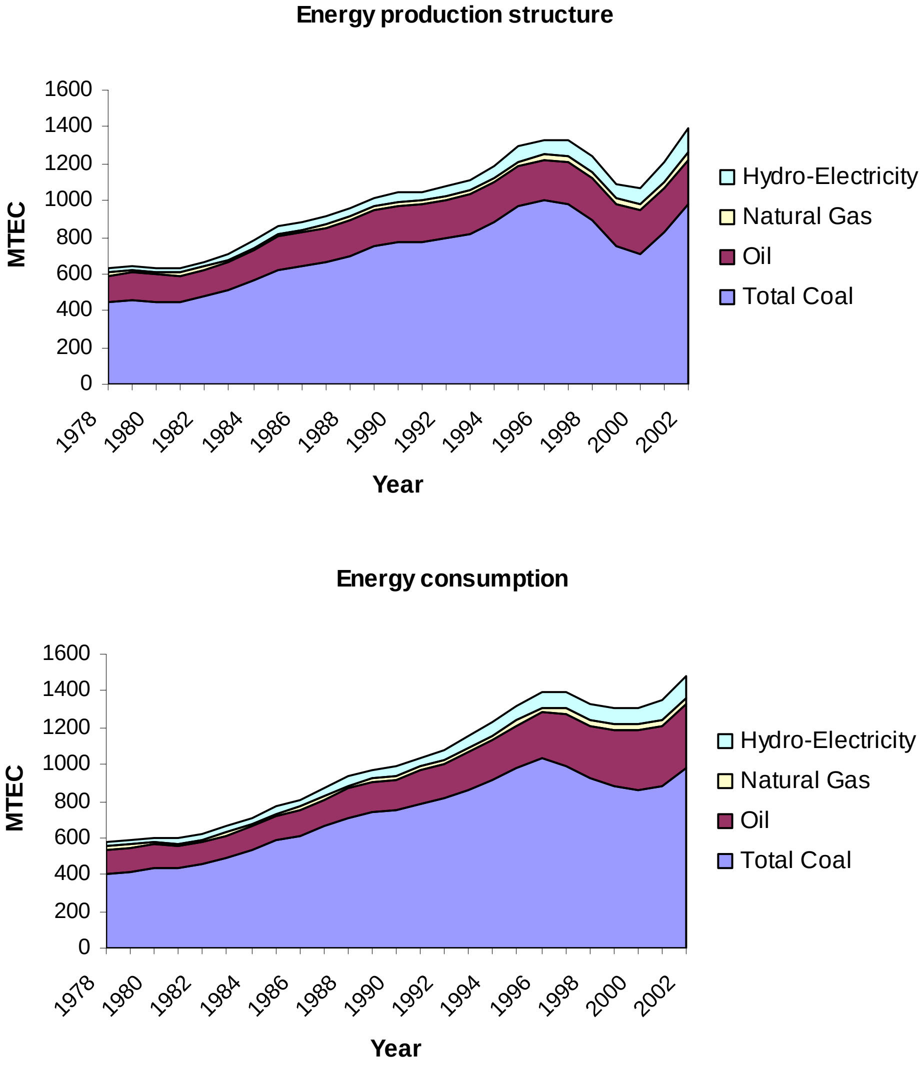
[3] "China suffers from high oil prices", *Alexander's Gas & Oil Connections*, vol. 8, issue#5, Thursday, March, 6th, 2003.

[4] See Aufhammer (2004ab) for overviews of these emergent trends.

2001, 30% of China's oil consumption is from import. China has since replaced Japan (a country with more than twice the GDP which is 94% import dependent) and become the world's second largest consumer of crude oil after the US.[5] As of the last quarter of 2003, IEA considered China to be the "main driver of global oil demand growth". We believe that given China's current population size, relatively low income level, and further economic growth potential, China's thirst for oil will be strongly amplified by the tandem processes of industrialization and modernization (see again Table 1). By 2030, China's net oil imports are expected to meet 80% of domestic demand, while just over a decade ago China was a net exporter of oil. In the absence of very elastic world supply for crude oil, we can expect Chinese demand to be a primary driver of rising global oil prices. Based on past experience with energy price spirals, this trend poses the risk of pervasive adjustments in world trade and economic structures.

Figure 2. The structure evolution in energy production and consumption

Data sources: China's Energy databook 5.0 and Chinese Statisitic Yearbook



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[5] IEA, 2004.

Figure 3. Evolution of China's energy demand and supply

Data sources: China's Statisitic Yearbook

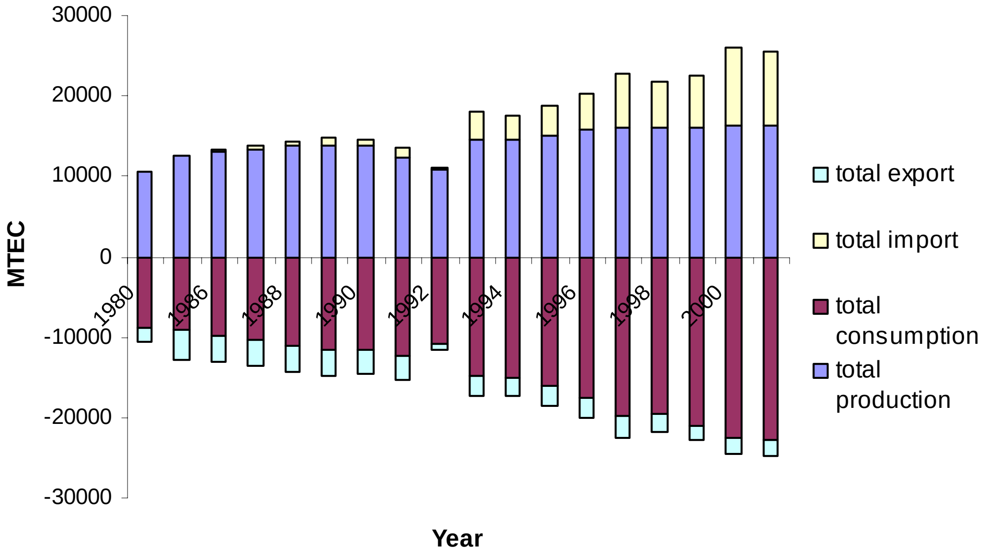
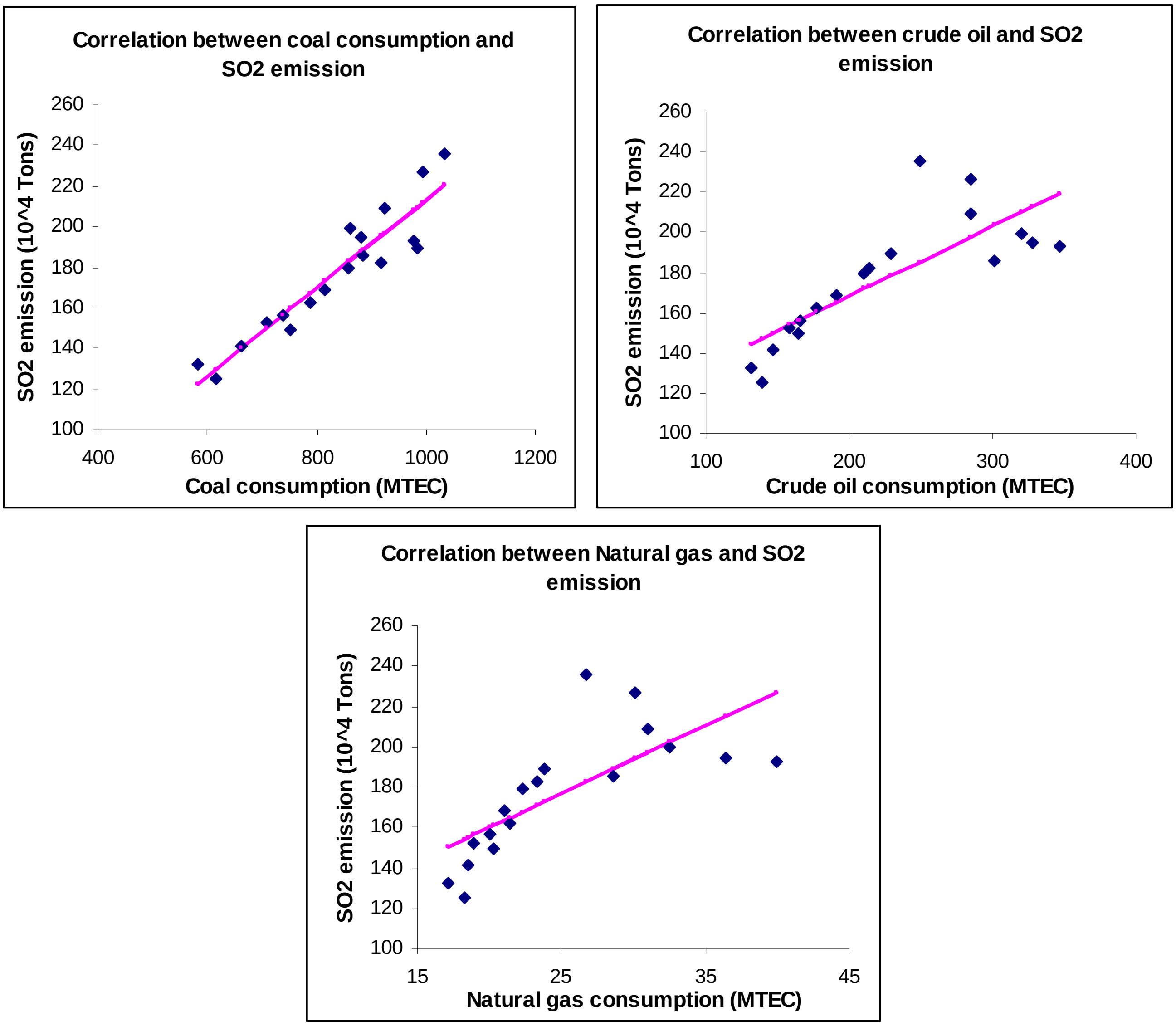


Figure 4. The possible correlation between fossil fuel consumption and SO_2 emission

Data source: China's Statistic Yearbook, China's Energy Databook 5.0



In addition to concern about domestic and global effects of China's rising oil dependence, the environmental consequences of China's oil use and other economic activities are also an import issue. Because of data and space constraints, the present paper concentrates on SO_2 emissions, generally considered as the most serious pollution problem in China. Because of industrial concentration and high population density since the 1980s, SO_2 pollution in China's urban areas has increased dramatically. In over one third of large Chinese cities, SO_2 concentration levels are at least twice the safe standard fixed by the WHO (World Health Organization) for the developing countries.[6] Some studies have already measured the adverse impact of SO_2 pollution on public health in China, especially as a significant cause of respiratory diseases.[7] Meanwhile, an ever-expanding problem of SO_2-induced acid rain both south and north China has resulted in rapid undercut both soil and capital productivity.[8]

Emissions of SO_2 generally come from fossil fuel combustion without abatement measures needed to reduce sulphur. For obvious reasons, China's SO_2 pollution problems are directly adducible to her rich reserves of bituminous coal. This link is especially apparent in the south-west, where the most serious incidences of SO_2 pollution and acid rain coincide with the country's most sulpherous coal deposits. The parallel movement of total SO_2 emissions (Figure 1) and the total energy consumption (Figure 3) suggest correlation between SO_2 emission and energy consumption. Based on direct estimation, in Figure 4, we present three graphs showing Chinese fossil energy consumption and SO_2 emission situation during last 25 years. Clearly, the most significant positive relationship exists between coal consumption and SO_2, while both oil and natural gas trends exhibit efficiency exhibits somewhat less important links with SO_2 emission.

3. Overview of the Model

The computable general equilibrium model we use is dynamic recursive. The dataset to which the model is calibrated is built around a 1997 Chinese social accounting matrix with 56 sectors, 14 agriculture sectors, 29 industrial sectors (of which four are energy sectors: coal mining, oil and coke, natural gas and electricity generation), one construction sector and 11 service sectors. The model is composed of production, income determination and consumption, government revenues and saving, trade, domestic supply and demand, market equilibrium, and macro closure rules and dynamic transition equations.

Production technology is specified at the sectoral level to combine capital, labor, natural resource, land, electricity, fossil fuels and other conventional intermediate inputs in production. We use a 6-layered nest of constant elasticity of substitution (CES) value added, combined with Leontief intermediates to specify production in a specific sector.[9] Our production specification distinguishes an energy bundle from other intermediate inputs and allows for continuous substitution between them. In light of the differing emission properties of, e.g. fossil fuels and electricity, we specify a CES decomposition between electricity and a fossil fuels bundle (coal, crude, petrol and coke, natural gas), assuming greater substitutability between fuels than with respect to electricity.[10] Considering the close link between fossil fuel use and SO_2 emissions, we assume in the present specification that only fuel combustions in production activities emits SO_2 pollution. This energy-substitutability arrangement frees us from the rigid energy input-

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[6] China's Environment Statistics (1998).

[7] Xu et al,1994, Wells, Xu et Johnson, 1994 and World Bank, 1996a.

[8] World Bank, 1996b.

[9] The production nesting is explained schematically in Appendix 1.

[10] Yang (2001) has made a similar arrangement for the energy substitution.

output ratios and admits substitution within the energy bundle and between energy and capital, labor, land and other resources used in production. These features enable producers to adapt to mitigation policies without proportional output reductions, and is more consistent with evidence on structural adjustment and energy efficiency growth.

The emission rates we use to impute SO2 pollution from energy use in production were obtained by direct estimation form Chinese industrial data. Using a time series detailing emissions and energy use for 18 sectors representing over 98% of the total industrial production), we obtained the estimates shown in Table 2. As was apparent in Figure 4, the most significant relationship exists between coal combustion and SO_2 emissions, and we see a lesser, but still significant between oil, petrol, and coke use and SO_2 emission. The insignificant negative coefficients for natural gas input supports conventional intuition that this is not a significant threat to the environment. Since the Hausman test suggests the superiority for random effect result, we use RE results to continue our analysis.[11]

TABLE 2. Energy induced SO2 emissions

Dependant variables: Industrial SO_2 emission (ton), panel data estimator (1991-1998, 18 sectors)

Explicative Var.[1]	Random Effect (RE)		Fixed Effect (FE)	
	Coefficient	T-value	Coefficient	T-value
Coal	0.0181581	5.17***	0.0184979	5.12***
Oil, petrol and coke	0.0099582	1.40*	0.011331	1.51*
Gas	-0.0083825	-0.88	-0.0098472	-0.99
Year	-5830.464	-0.63	-6596.19	-0.70
Constant	1.20×10^7	0.64	1.35×10^7	0.72
Breusch-Pagan test	479.02 (0.000)			
Hausman test	0.47 (0.9763)			
R^2 adjusted	0.2254		0.2254	
Num. of Group	18			
Num. of obs.	144			

Note: [1] the energy usage is measured in physical units, that is to say, TCE (tons of coal equivalence).

As the energy data used in these estimates are measured in physical units – TCE (tons of coal equivalence), we transform this into emission ratios for per monetary units of energy input obtained from the 1997 SAM. This is done using the corresponding value of total consumption for each type of energy inputs in all the manufacturing sectors in 1997 SAM, dividing these into the total energy input consumption for all the manufacturing sectors in physical unit recorded in the panel database to get the necessary conversion factors. This procedure is shown schematically in equation (1).[12] The conversion factor from physical to monetary units for emission rates for each energy input are given in Table 3.

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[11] Because of data constraints, we have to combine the crude oil, petrol, and coke together to complete our estimations.

[12] It is transformed from CNY by PPP exchange rate 1 USD=4.078 CNY. The PPP exchange rate is from Roland-Holst and Van der Mensbrugghe (2002).

$$\underbrace{\frac{SO_2emission}{energy(moentary)}}_{\substack{\text{Emission rate for}\\ \text{each monetary unit}\\ \text{of energy}}}=\underbrace{\frac{SO_2emission}{energy(physical)}}_{\substack{\text{Emission rate for}\\ \text{each physical unit}\\ \text{of energy}}}\times\underbrace{\frac{energy(physical)}{energy(monetary)}}_{\textbf{Conversion factor}} \tag{1}$$

TABLE 3. Conversion factor and emission rate per monetary unit of energy input

	Conversion factor (Inverse of energy price, CET tons/million USD)	SO_2 emission rate of the energy valued at million USD (Tons of emission/million USD)
Coal	35925.483 (27.84 USD/Ton CE)	652.339
Oil, petrol and coke	3858.622 (259.16 USD/ Ton CE)	39.421
Gas	19417.549 (51.50 USD/ Ton CE)	0

Note: Physical intermediary energy consumption data for total industry come from China's Energy Databook 5.0, LBL) and the monetary intermediary energy consumption data are from the 1997 SAM (Roland-Holst and van der Mensbrugghe, 2002).

We can now derive the SO_2 emissions for each sector by using the emission rate per monetary unit's energy and the detailed energy input consumption information furnished in SAM 1997 as equation (1). The total emission of SO_2 in the economy is calculated from equation (2). Here the index i refer to different sectors.

$$SO_{2i}=652.339\times Coal_i+39.421\times Oil_i+39.421\times petrol\&coke_i+0\times gas_i+0\times Electricity_i \tag{1}$$

$$SO_2=\sum_i SO_{2i} \tag{2}$$

Because of data constraints, the present model has only one household group. Each household's consumption decision is characterized by the Linear Expenditure System (LES) after a fixed share of the income is transferred in remittances and another fixed proportion goes to savings. Other domestic demand includes government final consumption, investment and the volume of services exported in international trade and transport activities. Unlike households, other final demand for different goods is determined by constant proportions with respect to the aggregated institutional income (revenue and savings, respectively).

The model assumes imperfect substitution between goods of differing origin and destination in trade. We use two-stage Armington (CES) functions form to determine demand composition between domestic and the imported goods from different origins.[13] On the supply side, domestic production is allocated across different markets by a two-stage constant elasticity of transformation (CET) specification. The trade distortions against export and import flows are specified as export taxes (or subsidies) and ad valorem tariffs and/or NTB (with calibrated premia) imposed by government, differing between different markets and assumed to be exogenous.

We assume domestic product demand achieves equality with domestic product supply by adjustment of domestic market prices. For the import demand, most goods are assumed to follow the small country assumption, perfectly elastic import supply and export demand, so in these cases world prices remain constant. Considering the reality of China's increasing share in total world oil import, it would be more plausible to allow for some price influence arising from

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[13] More details in the elasticity of substitution the Armington elasticity and the constant elasticity of transformation (CET) for each product are in the Appendix 2.

China's crude oil import demand. In particular, we suppose the volume of crude oil import supply to China is actually determined by the difference between the price offered by China and that of the world market. This can be expressed alternatively as equations (3), (3') and (4).

$$XMS_{k,r} = \alpha^M_{k,r} \left(\frac{WPMV_{k,r}}{WPM_{k,r}} \right)^{\eta^M_{k,r}} \quad \text{if } \eta^M_{k,r} \neq \infty \qquad \text{(Large country hypothesis)} \qquad (3)$$

$$WPMV_{k,r} = \overline{WPM_{k,r}} \quad \text{if } \eta^M_{k,r} = \infty \qquad \text{(Small country hypothesis)} \qquad (3')$$

$$XMS_{k,r} = XM_{k,r} \qquad \text{(Equilibrium price for import)} \qquad (4)$$

Where $XMS_{k,r}$ is import supply of product k from region r, $\alpha^M_{k,r}$ is an import supply shift parameter, $WPMV_{k,r}$ indicates the CIF price offered by Chinese importer, $\overline{WPM_{k,r}}$ refers the world market price for product k from region r and $\eta^M_{k,r}$ denotes the price elasticity of import supply from region r for product k. The variable $XM_{k,r}$ denotes Chinese import demand for product k from region r. The equation (3) and (3') determine the actual import volume for product k from region r and the equation (4) determines the equilibrium import price. Therefore, as the price offered by the Chinese importer rises, we see an increase in the volume of crude oil import going to China, depending upon the price elasticity $\eta^M_{k,r}$.[14] For export demand for Chinese products, we follow the small country hypothesis, i.e. world prices for export are assumed to be exogenous and export demand from China is perfectly elastic.

All factor markets, labor, capital, land, energy, and other specific resources are supposed to clear in equilibrium. Since the current data do not permit us to distinguish between labor of different skill levels, we assume labor to be perfectly mobile between sectors, determining a unique equilibrium wage. We suppose that capital is allocated with a CET specification across different sectors according to real rental rate differences. Land supply is fixed in the aggregate; the land allocation between different sectors follows a CET arrangement analogous to capital. Some resources are employed uniquely in specific sectors, such as the mines for coal mining sector, etc. In the model, we assume zero-mobility for these resources and their supply varies with their price relative to the general price index. For example, in light of China's limited proven capacity for crude oil extraction, we suppose the price elasticity for the supply of resource specific to the oil sector to be relatively small compared to the other sectors.[15]

Government revenue comes from a variety of fiscal instruments: production tax, intermediate consumption tax, income tax, final consumption tax, valued added tax, import tariff, net export tax (or subsidy), emission tax, and transfer from foreign countries. Its expenditure is consists of government consumption, transfers to households, enterprises, and to the rest of world. The residual of revenue over expenditure constitutes government's saving.

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[14] We suppose $\eta^M_{k,r}=50$ for both crude oil and petrol and coke products. The choice for the price elasticity of import supply $\eta^M_{k,r}$ values are based on experiments to equalize simulated import and domestic supply ratios in the crude oil sectors with actual data during 1997-2003 and also with independent projections of their shares to 2030. (see "China unable to quench thirst for oil", *Financial Time*, January 20, 2004. See the website at: http://news.ft.com/s01/servlet/ContentServer?pagename=FT.com/StoryFT/FullStory&c=StoryFT&cid=1073281160569&p=1012571727102).

[15] Same as the price elasticity for import supply, the choice of this price elasticity for the supply of oil sector specific natural resources also comes from simulations to match the domestic production share of the crude oil with data for the past years (1997-2003) and then to independent estimates for 2025.

In the model we consider all the tax rates as exogenously specified policy instruments, with initial values calibrated from the baseline SAM. Treatment of the emission tax is somewhat special since this tax is not accounted for separately in the original SAM. To included this policy instrument into model specification and SAM, we divide 1997 total SO_2 emission charges by total SO_2 pollution in all the *industrial and service* sectors, calculated from equation (2). This imputation yields a "national-wide average SO_2 levy rate", about 22.22 Yuan per ton of SO_2 emission. Next, we transform this average SO_2 emission rate into the energy-specific SO_2 emission tax rate by multiplying it by effluent rates for different energy sources. This component, energy-specific SO_2 emission tax rate will then enable us to calculate the SO_2 emission levy revenue from each industrial and service sector for the year 1997. This is done by multiplying the component coefficients by actual energy input use in each sector, which in turn is further separated from the total producer tax payments of each sector.

In the macro closure, we assume the government fiscal balance is exogenous, with the real value of government saving constant and the surplus of government revenue redistributed to households in lump-sum fashion Investment is driven endogenously in the model total savings coming from household, enterprise, government and the rest of world. The trade balance is also supposed to be endogenous, as is balance of payments, since we recognize a fixed exchange rate system for RMB in the model.

East Asia' dynamic growth experience has led many observers inside and outside the region to conclude that expanding trade confers a variety of growth externalities on outward oriented economies. Certainly China's economic growth history during the last 20 years and the general experiences from the Southeast Asia's four dragons seem to support this intuition. Traditional CGE models can capture simple aggregate efficiency gains from removing trade and other price distortions.[16], In our model, we have gone a little further to specify a positive growth externality arising from trade (through both exports and imports) and increasing domestic productivity. Since this is not the central topic of the present paper, detailed specification for the trade externality is included in an appendix.

4. Baseline and Policy Scenario

The main objective of this analysis is to see how China's economic growth process influences atmospheric pollution and to identify and quantify the effects of policies aimed at controlling and reducing this pollution. At this preliminary stage of analysis, we work only with a baseline dynamic scenario, where the available statistic data on growth rate of GDP and population and labor forces growth during 1997-2002 are used to reproduce historic growth trends over the years after our benchmark year 1997. Over the next 20 years (2003-2025), we calibrate out baseline to median independent estimates, with China will firstly growing by 7% annually till 2010 (the WTO accession period), followed by yearly growth rate of 6% until 2025. The detailed population and labor forces growth rates come from the projected information from UN's POPIN data (see Table 5 for more details). The necessary endogenous productivity growth rates used in industrial and service sectors to meet the forecasted GDP growth trajectory are also reported in Table 5.[17] Here, we also assume energy inputs enjoy the same productivity growth rate as capital and labor. To take account of Chinese trade

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[16] See, e.g. , De Melo and Robinson (1990) for South Korea, and Rodrigo and Thorbecke (1997) for Indonesia.

[17] We suppose that agriculture sectors do not share the same productivity growth rate and their productivity is supposed to be constant and exogenous in all the simulations, so are those for land and sector-specific natural resource. This is undoubtedly too pessimistic, and may induce adverse shifts in resources and domestic terms of trade, but we are working only with a baseline scenario at this stage.

liberalization with her WTO accession, we added the import tariff and NTB phasing-out and export tax reduction to this baseline (the detailed tariff and export tax reduction scheme is recorded in Appendix 4). All the other policy instruments are exogenously fixed in this baseline dynamic simulation, including the SO_2 emission levy rate, which is \ permitted to vary between 1997-2002 to capture the observed pollution reductions achieved during these years and then assumed to be unchanged during 2003-2025. We also assume an average capital depreciation rate 5%.

Table 5. Important exogenous variables in the baseline scenario

Exogenous variables	Year	Annual growth rate	Endogenous variable	Year	Annual growth rate
GDP (percent)	1997	8.8	Productivity growth path to meet the expected economic growth during 1997-2025 (reference to preceding year)	1998	2.75
	1998	7.8		1999	3.89
	1999	7.1		2000	2.78
	2000	8.0		2001	4.55
	2001	7.3		2002	3.17
	2002-09	7.0		2003	2.83
	2010-25	6.0		2004	3.01
				2005	3.26
				2006	4.23
				2007	3.5
Population (1/1000)	1997	10.06		2008	4.33
	1998	9.14		2009	4.54
	1999	8.18		2010	3.62
	2000	7.58		2011	4.21
	2001	6.95		2012	3.99
	2002	7.00		2013	4.44
	2003-15	6.06		2014	4.57
	2016-25	3.09		2015	4.64
Labor Force (Percent)	1997	1.82		2016	4.88
	1998	0.98		2017	4.61
	1999	1.65		2018	5.03
	2000	0.60		2019	4.96
	2001	1.25		2020	5.34
	2002-04	1.58		2021	5.31
	2005-10	0.66		2022	5.28
	2011-15	0.06		2023	5.2
	2016-20	-0.01		2024	5.09
	2021-25	-0.05		2025	4.93

5. Computational Results

The macroeconomic effects, SO_2 emissions changes, and results for energy use obtained from our baseline simulation are listed in Table 6. We first present their variations over the last eight years (1997-2004) and those for 20 years ahead (2005-2025) are then grouped into four 5-year sub-periods. If China's real GDP were to follow the assumed median growth rate path, we see that real GDP and GDP per capita will both more than triple over the next 25 years. At the same time, real disposable income will also increase more than 2.5 times. Total private consumption, parallel to income growth, will also triple by 2025 with respect to 2005, where the most important increases are in the consumption of manufacture goods (3.8 times higher) and services (3.5 times higher).

Economic Effects

We can identify obvious structural transformation in Chinese economy in these simulation results. From the beginning, the share of the aggregate output from agriculture will decrease monotonically. Then in all the four future sub-periods (assuming no productivity growth), its negative average yearly growth rates indicate that absolute production levels in agriculture will contract at an accelerating rate. Industrial sectors, including manufacture and construction, will first rapid expansion during 1997-2005 and 2005-2010. Although they remain the most important sectors of the economy in terms of absolute output and continue expanding, after 2010 these two sectors see monotone declines in aggregate output shares. For example, the annual growth rate of manufacturing will drop from 6.13 percent over 2010-2015 to 5.29 percent over 2015-2020, ending with only 3.87 percent annually over the last sub-period of 2020-2025. During the same time, we observe the opposite trend for annual growth rates of service sectors, which will surpass those for industry to become the most important in the whole economy from 2010. This expansion trend of service sector seems to be continued and reinforced further during the last two sub-periods, indicating the transition of China from industrial intensity to a more mature, service oriented economic system. We can see the trends toward post-industrial transition clearly in Figure 5.

Reduction in agriculture production will increase China's dependence on imports food and other agricultural products. This effect is most evident during the 1997-2010 periods, when Chinese population growth attains its maximal level. Because of tariff and NTB phase outs and export tax reductions promised for WTO adhesion, China will profit most from export and import growth during 2000-2010 period, with both total export and total import rising over 12% each year. Since the consumption structure's transformation will be relatively more stable than that of production and the demands for the manufacture and service products seem to parallel movements income growth, production structure changes actually are driven more by export and import variations. Corresponding to rapid service sector expansion, we also see dramatic in service sector exports, rising by more than 17% each year. This service sector growth is a typical companion of dynamic and export-oriented growth, where trade expansion is mediated by complex distribution and marketing services and strong multiplier linkages thereto.

Effects on Atmospheric Pollution

Without more extensive and intensive emission control policies, total SO_2 emission will increase significantly with China's economic growth However, our results indicate that the impact of growth on emissions differs between the first 3 sub-periods and the last two. During 1997-2015, the growth rate of real GDP and aggregate output are both higher than that of total SO_2 emissions, revealing a reduction of emission intensity at the aggregate level. However, during the last sub-period 2020-2025, the growth rate of total emissions is notably higher than its aggregate economic growth counterparts. A parallel situation can also be found for SO_2 emissions from manufacturing and service sectors. Figure 6 shows the annual variation in SO_2 emissions, real GDP, and SO2 emission intensity in the aggregate. Diverging from relatively stable economic growth, total SO_2 emissions trend upwards from 2015. This means SO_2 intensity forms an inverted U curve, with the minimum around year 2015.

Since these results contradict more optimistic scenarios, like those more congruent with the Environmental Kuznets Curve, they deserve closer inspection.[18] The cause of this trend in SO_2 emission intensity can be identified in more detailed results on energy consumption. Table 6 also shows a general slower growth rate in coal consumption with respect to the other three

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[18] A good general treatment of the EKC can be found in Andreoni and Levinson (2000).

fossil fuels and electricity. Since coal is the most polluting energy source in our empirical analysis, the divergence between coal and other energies' consumption tendency signifies gradual substitution for coal by other relatively less polluting energy. This is the principal reason for the decreasing SO_2 intensity during 1997-2015. During the last two periods, by contrast, we observe crude oil, petrol, and coke consumption rising faster than all the other energy sources. Since petroleum products are the second most important source of SO_2 pollution, we believe this is responsible for reversing the trend in aggregate SO_2 emission intensity.

Figure 7 shows the sectoral distribution of SO_2 emissions. Though manufacturing is still the most important SO_2 source, we observe a rapid increase in the share of SO_2 emissions from the service sector. This might be partially explained by China's structural transition, described in Figure 5, in which the share of service sector GDP expands. However, comparing Figure 5 with 7, we can see that the output shares do not appear to change enough to explain shifts in SO_2 emissions. Thus we still need to look more closely at sectoral emissions to understand the SO_2 trends.

Table 6. Macro variables and emissions

Macro economic factors	Real Values							Average growth rate (%)				
	Unit	1997	2005	2010	2015	2020	2025	1997-2005	2005-2010	2010-2015	2015-2020	2020-2025
Real GDP	10^9 US$	854.69	1532.53	2129.25	2848.95	3810.37	5096.73	7.57	6.80	6.00	5.99	5.99
Real GDP per capita	US$	691.36	1166.52	1572.49	2041.35	2689.51	3543.84	6.76	6.15	5.36	5.67	5.67
Aggregate output	10^9 US$	2280.77	3948.15	5321.63	6828.40	8692.86	10840.46	7.10	6.15	5.11	4.95	4.51
Agriculture	10^9 US$	263.03	301.92	297.72	286.58	264.14	231.36	1.74	-0.28	-0.76	-1.62	-2.61
Manufacture	10^9 US$	1337.69	2493.86	3575.65	4814.50	6229.47	7531.74	8.10	7.47	6.13	5.29	3.87
Construction	10^9 US$	210.22	430.01	629.77	854.37	1149.60	1528.47	9.36	7.93	6.29	6.12	5.86
Service	110 US$	469.83	815.16	1139.81	1591.29	2379.56	3603.81	7.13	6.93	6.90	8.38	8.66
Private consumption	10^9 US$	2290.10	4083.28	5686.35	7530.84	9997.44	13155.63	7.50	6.85	5.78	5.83	5.64
Agriculture	10^9 US$	265.32	346.45	405.32	468.09	546.35	643.47	3.39	3.19	2.92	3.14	3.33
Manufacture	110 US$	1342.87	2588.05	3800.32	5273.59	7278.32	9834.38	8.55	7.99	6.77	6.66	6.20
Construction	10^9 US$	211.19	433.64	637.57	867.51	1171.62	1564.45	9.41	8.01	6.35	6.19	5.95
Service	111 US$	470.73	803.84	1110.68	1489.05	2033.53	2805.23	6.92	6.68	6.04	6.43	6.65
Investment	10^9 US$	310.00	644.03	949.35	1291.26	1741.81	2320.78	9.57	8.07	6.34	6.17	5.91
Export	10^9 US$	235.93	581.18	1035.43	1661.18	2680.98	4284.48	11.93	12.24	9.92	10.05	9.83
Agriculture	10^9 US$	6.15	1.46	0.38	0.11	0.04	0.01	-16.44	-23.48	-21.61	-19.84	-18.40
Manufacture	10^9 US$	209.51	527.19	929.16	1428.81	2084.67	2987.07	12.23	12.00	8.99	7.85	7.46
Construction	10^9 US$	0.55	0.90	1.15	1.28	1.38	1.46	6.23	5.06	2.14	1.51	1.23
Service	10^9 US$	19.72	51.46	104.58	231.72	599.61	1308.92	12.74	15.24	17.25	20.94	16.90
Import	10^9 US$	245.26	678.82	1293.86	2098.39	3409.88	5466.69	13.57	13.77	10.15	10.20	9.90
Agriculture	10^9 US$	8.44	70.55	228.16	462.70	843.45	1426.37	30.40	26.46	15.19	12.76	11.08
Manufacture	10^9 US$	216.21	571.73	1021.21	1577.99	2478.02	3889.28	12.93	12.30	9.09	9.45	9.43
Construction	10^9 US$	1.52	4.61	9.43	15.62	26.26	43.67	14.86	15.39	10.62	10.94	10.71
Service	10^9 US$	20.62	39.02	71.09	112.42	187.96	318.03	8.30	12.75	9.60	10.83	11.09
Real disposable income	10^9 US$	750.34	1296.00	1745.27	2206.55	2827.34	3645.46	7.07	6.13	4.80	5.08	5.21
Per capita	US$	606.95	986.48	1288.91	1581.05	1995.65	2534.74	6.26	5.49	4.17	4.77	4.90

Table 6. Macro variables and emissions (Continue)

Emission and energy use	Real Values							Average growth rate (%)				
	Unit	1997	2005	2010	2015	2020	2025	1997-2005	2005-2010	2010-2015	2015-2020	2020-2025
Total SO2 emission	10^3 tons	8259.72	11946.48	14798.15	18458.86	25934.95	45903.24	4.72	4.37	4.52	7.04	12.10
Agriculture	10^3 tons	198.07	312.40	362.49	401.40	428.12	439.49	5.86	3.02	2.06	1.30	0.53
Manufacture	10^3 tons	7359.47	10460.49	12711.08	15326.15	20272.85	35568.53	4.49	3.97	3.81	5.75	11.90
Construction	10^3 tons	31.29	59.58	79.06	97.05	118.19	144.94	8.38	5.82	4.19	4.02	4.17
Service	10^3 tons	670.89	1114.00	1645.53	2634.26	5115.79	9750.27	6.54	8.11	9.87	14.20	13.77
Total coal input	10^6 TCE	333.23	436.39	495.49	546.55	614.17	750.41	3.43	2.57	1.98	2.36	4.09
Agriculture	10^6 TCE	5.57	7.78	8.38	8.43	8.03	7.05	4.27	1.49	0.12	-0.95	-2.58
Manufacture	10^6 TCE	315.64	414.40	471.75	521.90	588.89	725.27	3.46	2.63	2.04	2.44	4.25
Construction	10^6 TCE	1.14	1.92	2.32	2.59	2.81	2.93	6.74	3.88	2.22	1.63	0.84
Service	10^6 TCE	10.89	12.29	13.04	13.64	14.44	15.17	1.52	1.19	0.90	1.15	0.99
Total oil input	10^6 TCE	81.52	143.13	199.21	283.36	486.83	1211.05	7.29	6.84	7.30	11.43	19.99
Agriculture	10^6 TCE	0.06	0.09	0.11	0.11	0.11	0.10	5.83	3.23	0.81	-0.54	-2.09
Manufacture	10^6 TCE	81.34	142.89	198.95	283.11	486.59	1210.83	7.30	6.84	7.31	11.44	20.00
Construction	10^6 TCE	0.01	0.02	0.02	0.03	0.03	0.03	8.27	4.47	2.07	1.16	0.63
Service	10^6 TCE	0.11	0.12	0.12	0.12	0.11	0.10	0.91	-0.03	-0.99	-1.36	-1.31
Total petrol and coke input	10^6 TCE	134.59	250.48	368.47	551.86	959.97	1948.11	8.07	8.03	8.41	11.71	15.20
Agriculture	10^6 TCE	9.44	16.66	20.48	24.20	27.52	30.39	7.36	4.22	3.39	2.60	2.01
Manufacture	10^6 TCE	77.93	144.35	206.62	289.31	450.93	981.45	8.01	7.44	6.96	9.28	16.83
Construction	10^6 TCE	1.03	2.40	3.59	4.87	6.55	8.96	11.17	8.35	6.29	6.11	6.45
Service	10^6 TCE	46.19	87.07	137.77	233.49	474.97	927.32	8.25	9.61	11.13	15.26	14.32
Total gas input	10^6 TCE	21.54	33.84	41.34	47.34	52.94	60.70	5.81	4.09	2.75	2.26	2.77
Agriculture	10^6 TCE	0.01	0.02	0.03	0.03	0.03	0.03	6.83	4.49	2.38	1.06	-0.83
Manufacture	10^6 TCE	21.00	33.02	40.37	46.23	51.71	59.37	5.82	4.10	2.75	2.26	2.80
Construction	10^6 TCE	0.14	0.29	0.39	0.46	0.53	0.59	9.27	5.84	3.75	2.89	2.03
Service	10^6 TCE	0.39	0.50	0.57	0.62	0.67	0.71	3.09	2.52	1.79	1.55	1.18
Total electricity input	10^6 Kwh	1.00	1.92	2.72	3.63	4.78	6.56	8.47	7.17	5.95	5.67	6.55
Agriculture	10^6 Kwh	0.06	0.12	0.14	0.17	0.18	0.19	8.04	3.87	3.19	1.91	0.84
Manufacture	10^6 Kwh	0.85	1.63	2.34	3.15	4.18	5.82	8.58	7.42	6.13	5.85	6.86
Construction	10^6 Kwh	0.02	0.04	0.07	0.09	0.13	0.17	12.29	9.00	6.90	6.28	5.89
Service	10^6 Kwh	0.08	0.13	0.17	0.22	0.29	0.38	6.50	6.11	5.36	5.45	5.58

Figure 5. Sectoral distribution of total output

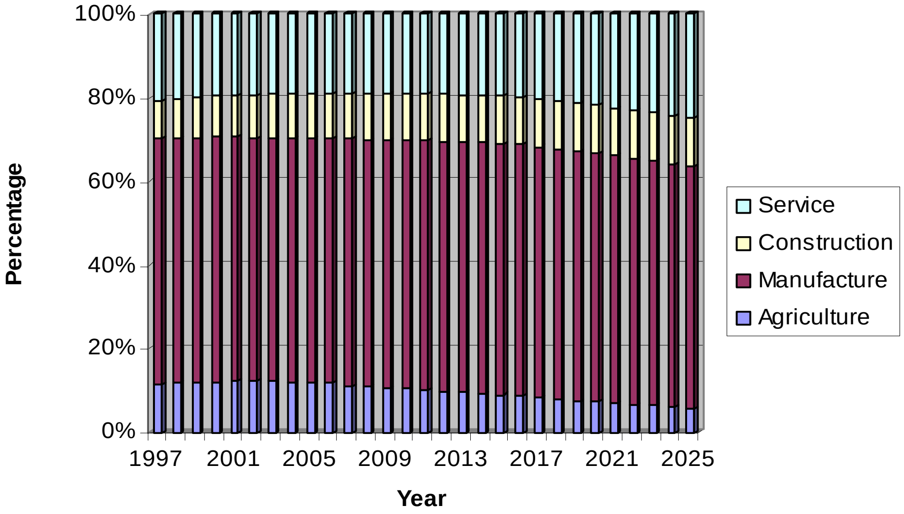


Figure 6. Projected SO2 emissions, Real GDP and SO2 emission intensity

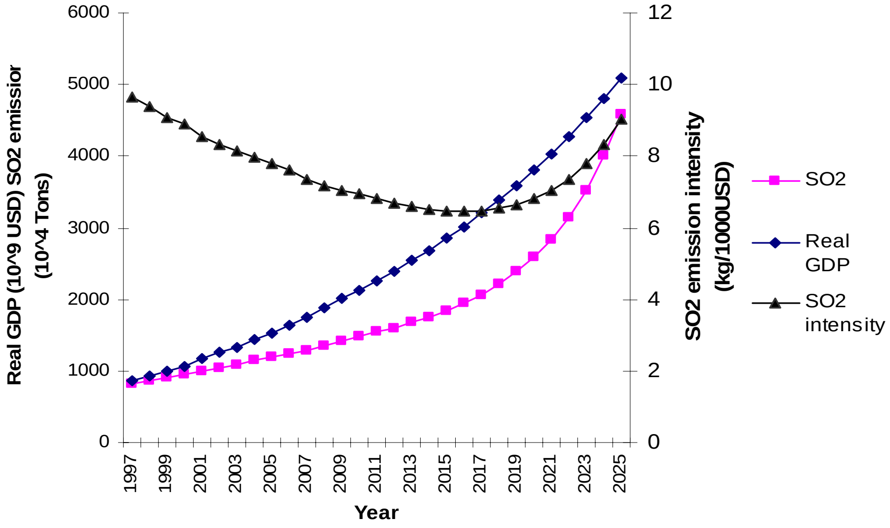
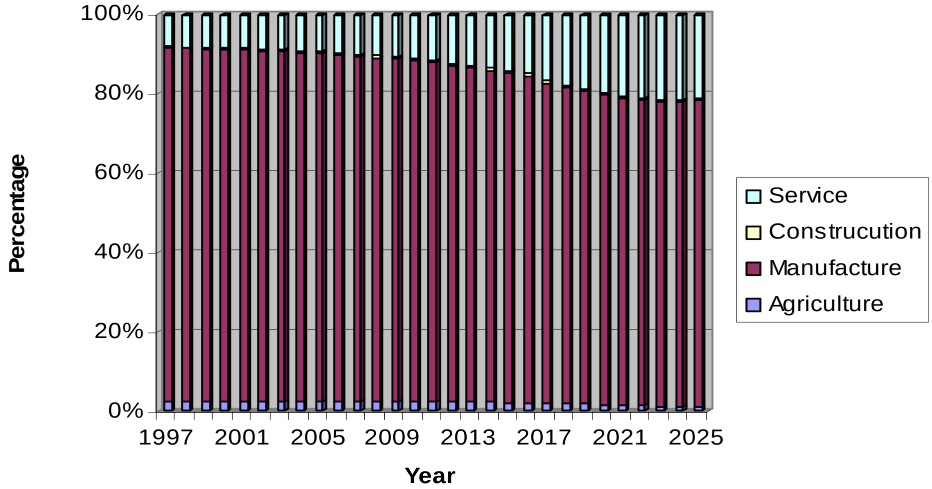
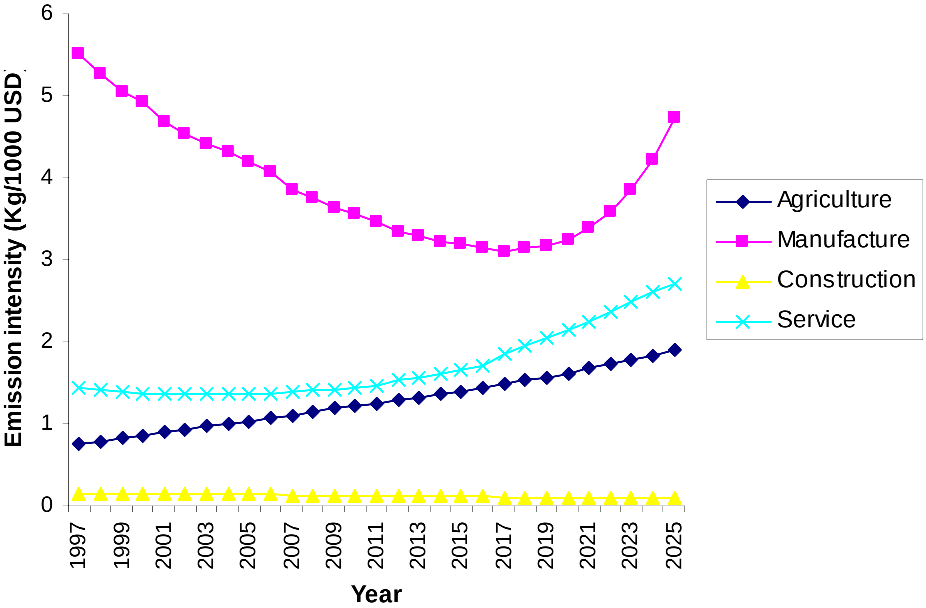


Figure 7. Sectoral distribution of SO2 emission



Comparison of Figures 8 with the sectroral emission share changes in Figure 7 provides useful insight into the process in question. During the early phase of growth, manufacturing dominates GDP and is experiencing rapid pollution efficiency gains. During the latter phase, structural transition steadily erodes the GDP share of manufacturing, but its pollution intensity is rising faster. This net adverse trend is reinforced by rising pollution intensity in services, whose GDP share is expanding to displace manufacturing. Agriculture experiences increasing pollution intensity, but its GDP share is declining faster.

Figure 8. Sectoral emission intensity

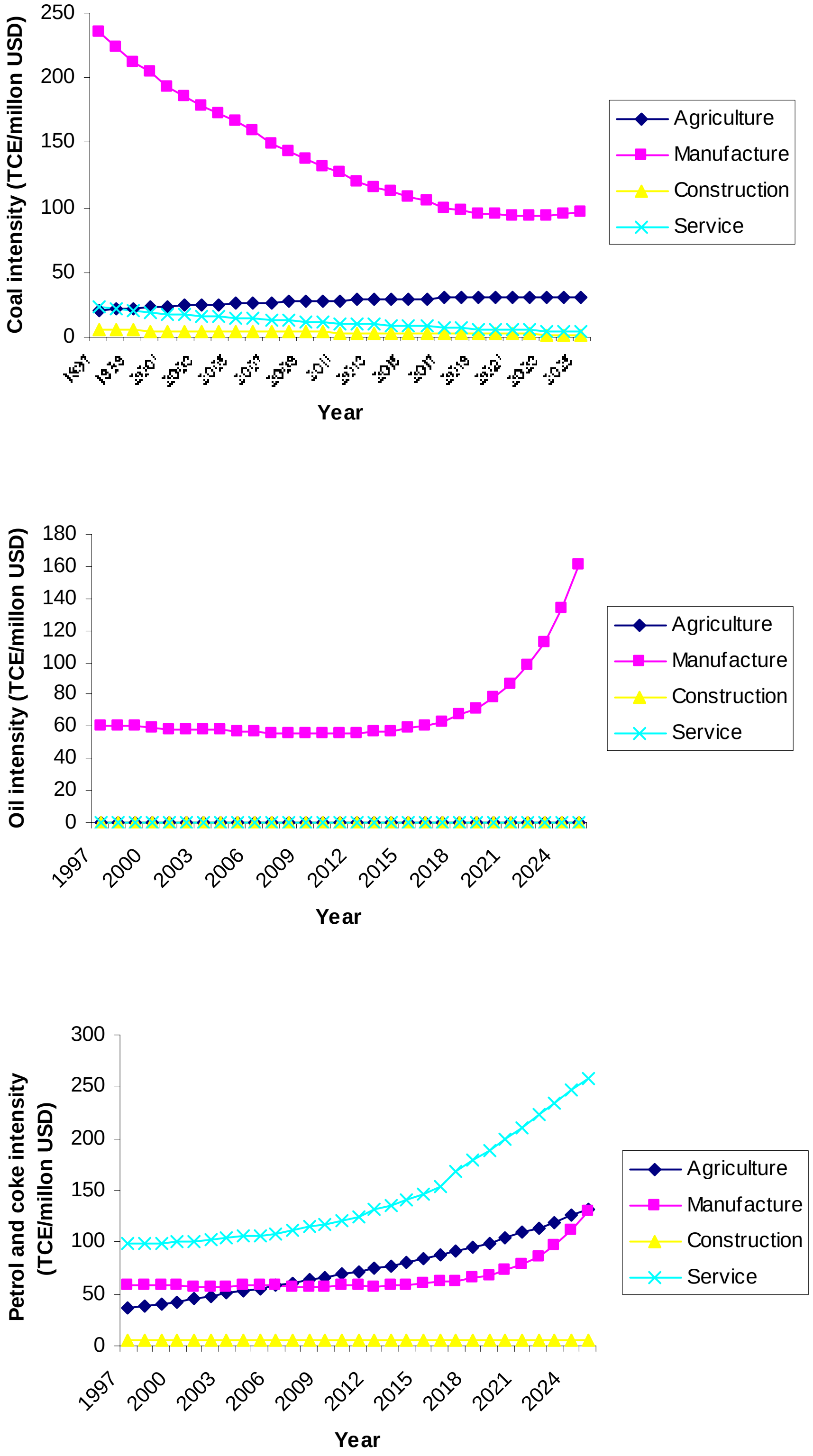


To further elucidate these variations in emission intensity, we show consumption changes for the three SO_2-related fossil fuels for all the four aggregate sectors in the Figure 9. Given that SO_2 emission is directly related to energy consumption (equation 1), SO_2 emission intensity is a combined result of emission from three fuel sources, coal, crude oil, and petrol and coke as follows:

$$\frac{SO_{2i}}{Y_i} = 652.339 \times \frac{Coal_i}{Y_i} + 39.421 \times \frac{Oil_i}{Y_i} + 39.421 \times \frac{Petrol\ \&coke_i}{Y_i} \tag{5}$$

Following this reasoning and comparing Figures 8 and 9, it becomes apparent that the early phase declines in manufacturing coal use, combined with the relatively stable crude oil and petrol and coke consumption intensity, are primarily responsible for decreasing trends in SO_2 emission intensity of this sector during the first three sub-periods. Unfortunately, the benefits of declining coal intensity are eventually overtaken by aggregate growth, with its attendant growth of other pollution intensive energy sources. In the present results, it appears that the latter trend more than offsets declines in the manufacturing share of GDP.

Figure 9. Sectoral energy intensity



Grossman (1995) considered industrial pollution as a “joint-product” of conventional output, the scale, composition and technical characteristics of which were pollutions three determinants. In our CGE model, by supposing the SO_2 emission to be directly related to energy consumption, we can capture these three determinants of SO_2 emission as

$$SO_{2\,i} = \sum_f \underbrace{\left(\frac{\varphi_f \times X_{f,i}}{X_i}\right)}_{Technique\ \ effect} \times \underbrace{\left(\frac{X_i}{\sum_i X_i}\right)}_{\substack{Composition \\ effect}} \times \underbrace{\sum_i X_i}_{\substack{Scale \\ effect}} \tag{6}$$

Where φ_f is a hypothetical constant emission rate from energy source f (estimated from Chinese data). The variable X_i denotes output in sector i and $X_{f,i}$ is the consumption of energy source f by sector i. The first term is the technique effect, which is actually an expression for emission intensity. The composition effect is represented by sector i output as a proportion of total output for the economy. The scale represents aggregate production for the whole economy. Next we decompose equation (6) to show how the change in SO_2 emission between period t and the initial period (0) is determined component variations as

$$SO_{2,it} / SO_{2,i0} = \left\{ \sum_f \left[0.5 \times \left(\frac{X_{f,it} \times \varphi f}{\sum_f (X_{f,it} \times \varphi f)} + \frac{X_{f,i0} \times \varphi f}{\sum_f (X_{f,i0} \times \varphi f)} \right] \times ln\left(\frac{\sum_i X_{it}}{\sum_i X_{i0}} \right) \right\} \qquad \text{(Scale)}$$

$$+ \left\{ \sum_f \left[0.5 \times \left(\frac{X_{f,it} \times \varphi f}{\sum_f (X_{f,it} \times \varphi f)} + \frac{X_{f,i0} \times \varphi f}{\sum_f (X_{f,i0} \times \varphi f)} \right] \times ln\left(\frac{\frac{X_{it}}{\sum_i X_{it}}}{\frac{X_{i0}}{\sum_i X_{i0}}} \right) \right\} \qquad \text{(Composition)}$$

$$+ \sum_f \left[0.5 \times \left(\frac{X_{f,it} \times \varphi f}{\sum_f (X_{f,it} \times \varphi f)} + \frac{X_{f,i0} \times \varphi f}{\sum_f (X_{f,i0} \times \varphi f)} \times ln\left(\frac{\frac{X_{f,it} \times \lambda_{it} \times AT_{it} \times BT_{it}}{X_{it}}}{\frac{X_{f,i0} \times \lambda_{i0} \times AT_{i0} \times BT_{i0}}{X_{i0}}} \right) \right] \right. \qquad \text{(Technique)}$$

$$+ residuals \tag{7}$$

This Divisia decomposition method has the advantage of revealing very detailed determinants of the three emission components. The sector-specific decomposition results for our baseline scenario are listed in Table 7. Since the 11 agriculture sectors only comprise a small share of SO_2 emission, we only report their aggregate contribution. To further clarify the the SO_2 emission trends, we divided the 1997-2025 period into three sub-periods, 1997-2003, 2003-2015 and 2015-2025.

As expected, the total manufacture sector contributes about 20242 K tons’ SO_2 emission growth during 2015-2025, which accounts for almost 74% of the emission increase. The other important part of emission growth comes from the service sector, contributing 7116 K tons and accounting for almost all the remaining 26% of total emission growth. Comparing these two figures with those over 2003-2015, we can see an obvious increase in the share of the service sector, whose emission share during 2003-2015 is only 22%.

It is useful to compare the two future periods with the historical baseline of 1997-2003. One common feature for manufacturing is concentration of SO_2 emission into the two energy sectors, electricity generation and petrol and coke. At the same time, the contribution from other non-energy sectors declines in relative terms. This reduction is especially notable for the heavy sectors as chemical products, other mineral, ferrous metals, other metals, and other machinery and equipment, all of which intensively use energy in their production. This finding suggests that with economic growth, China's industrial sector can gradually reduce dependence on raw energy such as coal, and substitute it with cleaner intermediate energy, such as oil products, gas, and electricity. This process can be identified in the negative entries in the technical effect columns of the both future periods.

From a structural perspective, another interesting commonality between the later two periods is a general reduction in GDP the share of heavy industries. This indicates a structural transition for China to greater labor intensity, corresponding to China's comparative advantages and may to a significant extent be trade driven. This phenomenon can be seen in the important and ever-increasing negative composition effect figures listed in both periods for the sectors as paper and publishing, chemical products, other mineral products, ferrous metals, other metals, metal products. At the same time, some traditional labour-intensive sectors, in which China originally possesses obvious comparative advantage, such as textiles, wearing apparel sectors, show gradual reductions of importance in the overall economic structure. On the contrary, some newly emergent labour-intensive sectors, especially electronic equipment, instead show important expansion. With income growth and improvement of live standards, some luxury durable product sectors, such as motor vehicles and other transportation equipment, also show expansion of their GDP share because of positive Engel effects.

To better understand the counter-intuitive total emission trend, more detailed examination of the service sector is revealing. Here we can observe important SO_2 emission contributions from composition changes. More precisely, the most significant composition increase is due to the rising share of three transport sectors (land, sea and air) in total economy. The expansion of these three is so strong that, even though their energy efficiency is improving significantly, we still observe important SO_2 emission from these sectors. Furthermore, the fact that these transport sectors intensively use petrol in their activities[19] contributes even more tellingly to SO_2 emission via induced expansion in the petrol and coke sector. As a intermediate energy producer, meeting increasing demand from the transport sectors will lead the petrol and coke sector to further increase output, contributing to a more than 50% increase of SO_2 emissions from this sector.

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[19] From our simulation results, we see the petrol and coke intensity for the three transport sectors are 302 TEC/Million USD, 680 TEC/Million USD and 282TEC/Million USD for the land, air and water transport sectors in Year 2025, respectively. While at the same time, the average petrol and coke intensity for the manufacture is 125 TEC/Million USD, and that for total economy is 169TEC/Million USD.

Table 7. Decomposition of changes in SO_2 emissions (Divisia decomposition)

Sector	2003 vs. 1997					2015 vs. 2003					2025 vs. 2015				
	Scale effect	Composition effect	Technique effect	Residuals	Total	Scale effect	Composition effect	Technique effect	Residuals	Total	Scale effect	Composition effect	Technique effect	Residuals	Total
agriculture	**102,41**	**-68,46**	**55,34**	**-0,12**	**89,15**	**226,31**	**-229,53**	**118,76**	**-1,35**	**114,17**	**197,76**	**-293,54**	**141,45**	**-7,58**	**38,09**
Manufacturing	**3592,64**	**1194,72**	**-2564,09**	**-4,59**	**2218,64**	**8155,66**	**4526,55**	**-6802,84**	**-131,35**	**5748,03**	**11058,81**	**22881,64**	**-10415,5**	**-3282,61**	**20242,38**
Coal	0,22	-0,11	-0,08	0	0,02	0,35	-0,2	-0,15	0	0,01	0,25	-0,1	-0,15	0	0,01
Oil	0,05	-0,11	-0,03	0,11	0,01	0,07	-0,03	-0,05	0	-0,01	0,05	-0,02	-0,02	0	0
Petrol and coke	517,45	269,72	-227,42	-4,43	555,32	1646,05	1759,56	-1063,67	-118,3	2223,64	4387,38	17093,69	-3302,67	-3340,85	14837,55
Gas	16,24	0,9	-8,75	0	8,38	30,92	-4,68	-18,38	-0,08	7,78	23,77	-9,22	-14,48	-0,14	-0,07
Electricity	1678,02	615,79	-1493,29	0,23	800,75	3473,94	2101,49	-3781,9	-6,83	1786,7	3899,71	5751,34	-5113,17	75,97	4613,86
Mining	20,45	4,09	-7,79	0	16,75	46,14	5,9	-26,16	-0,03	25,85	40,49	-7,48	-27,91	0,52	5,62
Bovine cattle, sheep	0,78	-1,32	-1,62	0	-2,16	0,32	-0,87	-0,22	0	-0,77	0,06	-0,13	-0,04	0	-0,12
Other meat products	0,74	-0,78	-0,69	0	-0,72	0,68	-1,02	-0,37	0	-0,7	0,28	-0,29	-0,19	-0,01	-0,21
Vegetable oils, fat	8,1	-5,57	-11,34	0	-8,81	7,41	-7,83	-6,54	0	-6,96	3,06	-2,78	-3,04	-0,03	-2,78
Dairy products	0,51	-0,35	-0,74	0	-0,59	0,49	-0,48	-0,35	0	-0,34	0,25	-0,13	-0,2	0	-0,09
Processed rice	21,8	-13,91	-24,46	0	-16,57	21,53	-27,28	-14,32	0,01	-20,06	7,83	-13,57	-6,16	0,07	-11,85
Sugar	0,11	-0,23	-0,31	0	-0,43	0,02	-0,1	-0,01	0	-0,09	0	0	0	0	0
Other food products	4,38	-3,44	-9,12	0	-8,19	3,23	-4,31	-2,3	0	-3,38	1,28	-1,32	-1,09	-0,03	-1,15
Beverages & tobacco	21,38	-2,64	-19,24	0	-0,51	31,29	-14,1	-23,21	-0,02	-6,04	20,2	-5,26	-16,87	-0,38	-2,3
Textiles	42,4	9,04	-29,79	0,01	21,66	81,09	0,79	-60,44	0,26	21,7	52,6	-49,21	-46,29	2,71	-40,19
Wearing apparel	5,99	3,56	-1,62	0	7,93	16,57	7,94	-10,53	0,06	14,05	13,17	-12,49	-10,02	0,52	-8,82
Leather products	2,42	-3	-1,79	0	-2,37	2,36	-3,26	-1,01	-0,01	-1,91	1,18	-0,81	-0,66	-0,04	-0,33
Wood	12,24	1,1	-6,98	0	6,35	24,31	0,22	-15,49	0,01	9,04	19,58	-3,63	-15,29	-0,06	0,61
Paper & publishing	36,75	-2,31	-22,58	0	11,85	67,06	-9,27	-41,42	0,05	16,42	51,35	-13,08	-40,35	1,56	-0,52
Chem. Prod	464,94	125,28	-284,37	-0,59	305,26	1032,23	213,48	-612,44	-6,31	626,96	971,16	-45,1	-546,26	-25,11	354,69
Other mineral prods	330,19	86,63	-173,98	0,04	242,88	755,12	222,49	-490,13	-0,17	487,29	724,93	153,53	-577,28	-11,63	289,54

Table 7. Decomposition of changes in SO_2 emissions (Divisia decomposition, continued)

Sector	2003 vs. 1997					2015 vs. 2003					2025 vs. 2015				
	Scale effect	Composition effect	Technique effect	Residuals	Total	Scale effect	Composition effect	Technique effect	Residuals	Total	Scale effect	Composition effect	Technique effect	Residuals	Total
Ferrous metals	257,05	62,74	-148	0,04	171,84	561,75	128,9	-378,33	0,2	312,52	500,26	11,83	-415,69	5,96	102,36
Other metal	31,66	10,02	-21,18	0	20,5	69,21	21,89	-51,68	-0,01	39,41	59,49	-8,81	-50,65	2,33	2,37
Metal products	14,05	3,6	-7,16	0	10,49	32,45	9,83	-20,61	-0,04	21,63	30,59	1,55	-23,1	0,07	9,12
Motor vehicles	11,17	1,94	-8,47	0	4,64	22,01	2,67	-15,59	-0,05	9,04	19,51	3,79	-15,19	-0,78	7,34
Other trans. equips	6,72	2,41	-3,39	0	5,75	16,95	9,05	-11,58	-0,06	14,36	20,97	18,59	-15,7	0,48	24,35
Electronic equipment	3,47	1,96	-1,43	0	4,01	14,5	23,13	-8,66	0,01	28,98	22,84	9,82	-18,56	4,88	18,99
Other mach & equip.	61,37	18,25	-33,71	0	45,92	142,63	52,05	-97,19	-0,09	97,4	138,05	19,97	-105,51	0,67	53,18
Other manufactures	20,88	11,06	-14,07	0	17,86	52,32	39,43	-48,36	0,08	43,47	45,47	-10,81	-47,46	1,12	-11,68
Water	1,11	0,4	-0,69	0	0,82	2,66	1,16	-1,75	-0,03	2,04	3,05	1,77	-1,5	-0,41	2,9
Construction	**17,37**	**5,13**	**-2,02**	**-0,02**	**20,46**	**48,27**	**12,91**	**-15,55**	**-0,33**	**45,3**	**56,64**	**14,03**	**-18,42**	**-4,34**	**47,89**
Services	**345,91**	**18,05**	**-61,18**	**-0,77**	**302,05**	**1083,18**	**844,24**	**-248,32**	**-17,74**	**1661,34**	**2505,72**	**5219,35**	**-544,23**	**-64,83**	**7116,01**
Trade	53,13	4,87	-6,21	-0,1	51,7	144,04	21,39	-22,78	-1,42	141,23	180,78	45,18	-16,25	-17,96	191,74
Land transport	121,35	32,14	-22,29	-0,28	130,92	360,67	153,88	-87,88	-4,68	421,99	545,13	438,7	-81,2	-53,68	848,94
Sea transport	36,33	25,46	-4,94	-0,19	56,66	230,26	476,83	-53,94	-7,96	645,2	1051,94	3302,55	-238,03	2,93	4119,39
Air transport	20,49	14,5	-3,97	-0,07	30,95	128,98	270,18	-34,85	-2,15	362,15	521,17	1446,47	-158,08	18,16	1827,72
Communication	2,73	1,19	-1,83	-0,01	2,1	7,3	4,12	-3,66	-0,11	7,65	9,27	4,25	-3,06	-0,89	9,57
Financial services	3,08	0,78	-0,84	-0,01	3	8,51	3,16	-2,76	-0,09	8,82	11,4	6,14	-2,08	-1,23	14,23
Insurance	0,82	0,25	-0,29	0	0,78	2,28	1,05	-0,89	-0,02	2,4	3,19	2,28	-0,77	-0,27	4,44
Business services	12,48	0,06	-7,21	-0,01	5,33	25,02	0,13	-13,72	-0,12	11,31	23,57	5,16	-13,03	-2,27	13,44
Recreation & services	9,46	0,72	-2,28	-0,01	7,89	24,16	5,72	-8,13	-0,14	21,62	29,6	13,41	-10,23	-1,18	31,6
Public services	86	-61,95	-11,29	-0,09	12,67	151,84	-92,35	-19,57	-1,05	38,87	129,55	-44,89	-21,34	-8,44	54,88
Dwellings	0,04	0,03	-0,03	0	0,05	0,12	0,13	-0,14	0	0,1	0,12	0,1	-0,16	0	0,06
Total	**4058,32**	**1149,4**	**-2571,93**	**-5,49**	**2630,3**	**9513,4**	**5154,19**	**-6948**	**-150,76**	**7568,84**	**13818,95**	**27821,47**	**-10836,66**	**-3359,38**	**27444,38**

6. Conclusions and Extensions

China’s economy has attained levels of growth and modernization that seemed beyond imagining only a generation ago. Along with its many successes in improving material living standards, however, have come new risks to sustainability and environmental quality. This paper, seeks to improve our understanding of how China can go “over the mountain” of industrial transformation without jeopardizing either its own qualities of life or those of others. With the aid of a dynamics CGE model, we examined the relationships between economic growth, structural transformation, energy use, and finally SO_2 emissions. It is readily apparent from our results that, without more effective emission control policies, China’s economic growth over the next generation will give rise to very significant SO_2 emission problems, especially in the period of 2015-2025. Our simulations show that, sustained growth and openness over the next 20 years will induce pervasive structure transformation in the Chinese economy. On one hand, we see an increase in the importance of the labour-intensive sectors, especially the emergent sectors as electronic equipment, accompanied by a decrease in the relative importance of polluting and energy-intensive heavy industries. At the same time, modernization of China’s economy will increase the share of service sector GDP and reduce that of manufacturing and agriculture.

However, contrary to some expectations, this structural transition may not ameliorate environmental conditions for China. Instead, we see an even greater atmospheric pollution challenge emerging from rapid and widespread expansion of the energy-intensive transport sectors. Having said this, we also observe a general tendency to substitute away from the most polluting raw energy sources. In this process, coal is significantly displaced by relatively cleaner intermediate energies such as electricity, oil products and natural gas in manufacturing. SO_2 emissions re-concentrate into intermediate energies sectors (electricity generation and petrol and coke sectors) from the other manufacture and service sectors. This actually confers an administrative benefit for emission control activities since they can concentrate their inspection and de-sulphur efforts on these main SO_2 sources. Our results indicate that, by targeting emissions from the two intermediate energy sectors, electricity and hydrocarbons (petrol and coke), a 70% reduction from these sectors can actually reduce the total SO2 emission from the whole economy by 50%.

By far the most important emergent emission source is transport services, and here it is clearly necessary to exert more strict emission controls. This sector currently has more limited energy substitution possibilities and its production is closely related to petroleum consumption. These considerations reinforce the importance and even urgency for the research and development activities on clean fuel (such as the natural gas, etc.) vehicle technologies in China. It should also be emphasized that our SO2 projections may be relatively optimistic because we have only taken partial account of emissions from personal motor vehicle use. Given the rapid expansion of the automobile demand in China, we need to add this capacity to the model.

Another consideration regarding expansion of the transport services comes from the trade side. Given China’s limited domestic crude oil reserves, increases in oil-intensive transport sector will unavoidably accelerate China’s oil imports. From Figure 10, we can see that due to the rapid increase in total oil consumption, especially for the period 2015-2025, the crude import ratio in total consumption will reach about 80%. Since we assumed in the model that China could influence the oil terms-of-trade, we also expected at least 10%’s increase in the oil price. As we work in a single country CGE model, we have not been able to consider the possibility that the world oil price might also be pulled upward due to China’s thirst for oil.

However, considering the already tightened supply situation for the crude oil in world market, China's oil needs will unavoidably drive up world prices in the future, leading to an upward spiral in energy markets.[20] At the macroeconomic level, the consequences could be severe for China, undermining both its trade balance and export competitiveness (as higher energy costs are factored into commodity prices). In a more general sense, then, it is an urgent priority to support R&D activities in for cleaner fuel transport and production, not only for the benefit of China but also that of the whole world.

Extensions of the present work are very numerous. Indeed, it can be said that this paper represents only a prototype exercise to showcase the research capacity of the underlying model and data. Here we only examine a single baseline scenario, without any reference to a wide array of counterfactual external trends or policy responses. Of course there is nothing inevitable about the median macro trend to which we calibrated the model, and it is certainly not reasonable to predict government passivity in the face of adverse environmental trends like the one we focused on here. For example, the current model includes an array of policy instruments that could be tested for the ability to mitigate pollution and other undesirable trends, and experiments like this will be part of our continuing research agenda. Our main objective here is to show how this kind of empirical simulation model can reveal the interplay between the complex market and institutional forces that will determine the ultimate outcomes for China in the decades to come. Hopefully, this kind of research capacity can support design and implementation of better policies ex ante, thereby averting more significant costs after environmental or other economic damage has been done.

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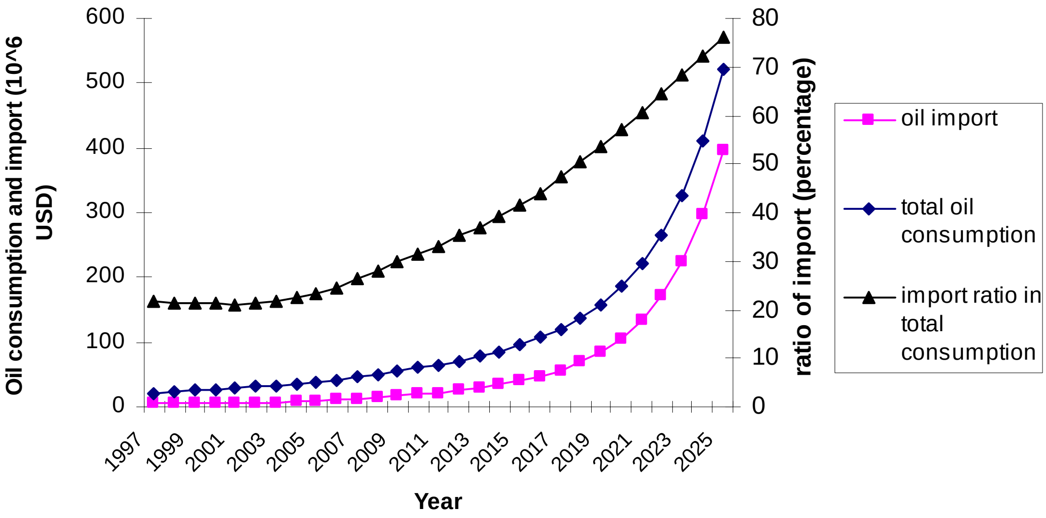
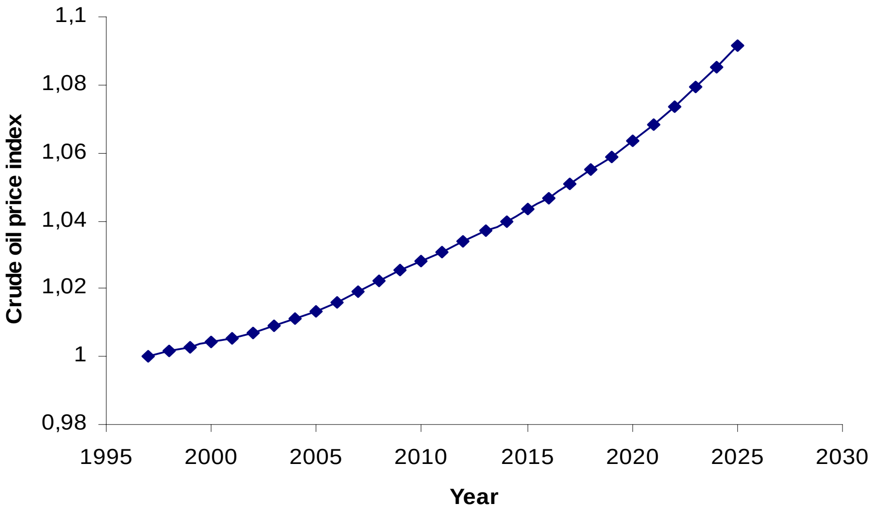
[20] This impact need to be tested in a world CGE model.

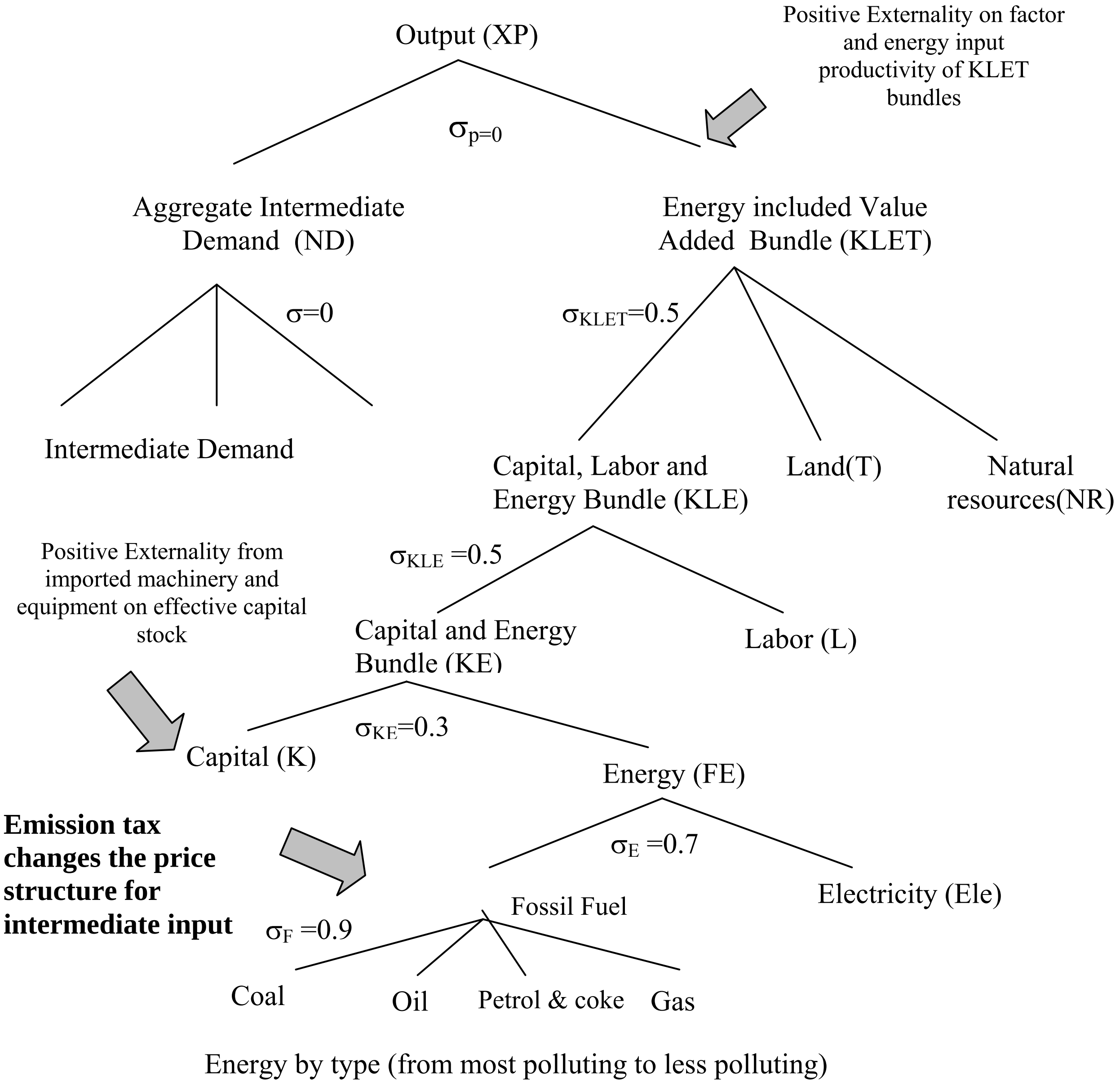
Figure 10. Crude oil and petrol consumption and import



igure 11. Crude oil price changes



APPENDIX 1. Production Structure



APPENDIX 2. Principal assumptions on the key model elasticity

For the substitution elasticity between intermediate consumption and the traditional and energy factors are furnished in Appendix 1.

Household income elasticities for different goods are obtained from Roland-Holst and van der Mensbrugghe (2002), which are originally coming from GTAP database.

Both the Armington elasticities between domestic and aggregate import demand and that between import demands across different origins are supposed to be 4.0. For the top-level transformation elasticity between the domestic market and aggregate exports and that between exports across different destinations, we also suppose them to be 4.0. Most of the choices of the elasticity conform to standards in the literature.

The crude oil and petrol and coke import supply elasticities are both supposed to be 50, which was chosen in a restricted calibration exercise.

To capture inelastic domestic production in oil sector, we suppose the price elasticity of the specific natural resource supply for this sector to be 0.3, which is relatively less important than those of the other sectors, which are generally supposed to be unity. In future work, we plan to subject all these parameters to sensitivity analysis.

Appendix 3. Modeling the trade externality

To capture the effect of a trade-driven growth externality, we experimented with the following approach:

Firstly, we assume that export orientation is associated with total factor productivity growth, either because of learning by doing, independent or partnered technology acquisition, or some combination of the two. To capture this in the model, we follow the model specification of Rodrigo and Thorbecke (1997) and modify production in the model is as in the following equation

$$Y_j = AT_j \left[a_k (\lambda_k \times K_j)^{\rho} + a_{ene} (\lambda_{ene} \times ENE_j)^{\rho} + a_l (\lambda_l \times L_j)^{\rho} \right]^{1/\rho} \qquad \text{(A3.1)}$$

where Y_j is the product, AT_j represents an export externality shift parameter in production. In the traditional CES production system, where a_x is the share parameter, ρ is CES exponent related to elasticity of substitution between production factors. The term

$$AT_j = \overline{AT_j} \left(\frac{\overline{E_k}}{E_{k,t-1}} \right)^{\varphi} \text{ with } \overline{AT} = 1$$

shows the productivity shift due to an increase in export volume, where the E_k denotes export volume for product k and the index t-1 refers to the preceding year. Following the experience of de Melo and Robinson (1990) in their research on Korea, we choose here a fairly small value of 0.1 for externality parameter φ to describe the export externality for China.

As China's new open policy facilitates the (duty free) import of foreign equipment embodying advanced technology, we also consider a positive externality arising from accumulation of imported capital goods. Given the close link between upstream and downstream sectors and the productivity growth coming from the effect of learning by "doing" and even learning by "watching", the positive technical progress effect of the imported machinery can, very possibly, spill over the frontier of the enterprise to reach all the production sectors. To capture this external effect, we further modify the production function as equation (b) where we suppose the increase in the stock of the imported machinery and equipment import will cause an actual increase in effective capital of the economy.

$$KLE_j = AT_j \left[a_k (\lambda_k \times BT \times K_j)^{\rho} + a_{ene} (\lambda_{ene} \times ENE_j)^{\rho} + a_l (\lambda_l \times L_j)^{\rho} \right]^{/\rho} \qquad \text{(b)}$$

where BT represents externality sourcing from the stock of import of advanced machinery and equipments. And mathematically, this import-externality shift parameter is given by

$$BT = \overline{BT} \times \left(1 + \frac{\sum_{hp} M_{hp,t}}{\sum_{hp} \sum_{T=0}^{t} M_{hp,T}} \right)^{\psi} \qquad \text{(c)}$$

Here $M_{hp,t}$ is the imported machinery and equipment of sector *hp* (all the machinery and equipment sectors) in period *t*, and $\overline{BT} = 1$. This equation indicates the primary drivers of the import externality, increases in the domestic total stock of imported equipment and machinery from the outset, when $t=0$. As the increase in the stock of the imported machinery will lead the volume of *effective* capital supply for the economy as a whole to increase to $BT \times K_j$, since we know that $BT \geqslant 1$, so $BT \times K_j \geqslant K_j$. Here the externality parameter ψ is supposed to be 0.1, following case of Indonesia studied by Rodrigo and Thorbecke (1997).

APPENDIX 4. Anticipated tariff reduction schedule for China

(Percents change from 2000, 2000=100)

Sectors	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
Paddy rice	83,66	68,28	53,87	40,62	37,62	34,62	31,62	28,63	25,63	22,63
Wheat	90,07	80,24	70,42	60,59	61,28	51,46	41,63	31,81	21,98	12,16
Cereal grains, n.e.s.	90,58	81,16	71,73	62,31	53,01	43,70	34,40	25,09	15,79	6,49
Vegetables and fruits	89,20	78,40	68,74	58,51	56,86	55,20	53,54	51,89	50,23	48,57
Oil seeds	89,89	79,77	69,66	59,55	50,66	41,77	32,88	24,00	15,11	6,22
Sugar cane and sugar	89,20	78,40	68,74	58,51	56,86	55,20	53,54	51,89	50,23	48,57
Plant-based fibers	80,90	72,05	63,21	54,36	64,74	55,90	47,05	38,21	29,36	20,51
Crops, n.e.s.	89,20	78,40	68,74	58,51	56,86	55,20	53,54	51,89	50,23	48,57
Bovine cattle, sheep	97,22	94,44	93,06	90,28	90,28	90,28	90,28	90,28	90,28	90,28
Animal products n.e.s.	97,22	94,44	93,06	90,28	90,28	90,28	90,28	90,28	90,28	90,28
Raw milk	90,79	81,58	72,37	63,17	61,15	59,14	57,12	55,11	53,09	51,08
Wool, silk-worm	90,79	81,58	72,37	63,17	61,15	59,14	57,12	55,11	53,09	51,08
Forestry	84,61	69,22	53,83	38,44	36,43	36,43	36,43	36,43	36,43	36,43
Fishing	84,61	69,22	53,83	38,44	36,43	36,43	36,43	36,43	36,43	36,43
Coal	78,94	64,70	50,45	36,21	21,97	21,97	21,97	21,97	21,97	21,97
Oil	78,94	64,70	50,45	36,21	21,97	21,97	21,97	21,97	21,97	21,97
Petrol and coke	78,94	64,70	50,45	36,21	21,97	21,97	21,97	21,97	21,97	21,97
Gas	78,94	64,70	50,45	36,21	21,97	21,97	21,97	21,97	21,97	21,97
Electricity	78,94	64,70	50,45	36,21	21,97	21,97	21,97	21,97	21,97	21,97
Other minerals	83,24	67,94	53,38	39,56	25,00	25,00	25,00	25,00	25,00	25,00
Bovine, sheep and	90,79	81,58	72,37	63,17	61,15	59,14	57,12	55,11	53,09	51,08
Other meat products	90,79	81,58	72,37	63,17	61,15	59,14	57,12	55,11	53,09	51,08
Vegetable oils and fats	85,00	76,36	67,73	60,00	52,27	44,55	36,82	29,09	21,36	13,64
Dairy products	90,79	81,58	72,37	63,17	61,15	59,14	57,12	55,11	53,09	51,08
Processed rice	85,00	76,36	67,73	60,00	52,27	44,55	36,82	29,09	21,36	13,64
Sugar	85,00	76,36	67,73	60,00	52,27	44,55	36,82	29,09	21,36	13,64
Other food products	85,00	76,36	67,73	60,00	52,27	44,55	36,82	29,09	21,36	13,64
Beverage and tobacco	86,42	72,85	59,27	46,00	34,85	31,21	31,21	31,21	31,21	31,21
Textiles	81,01	60,76	41,77	22,78	3,80	3,80	3,80	3,80	3,80	3,80
Wearing Apparel	80,35	62,46	42,81	23,16	5,26	5,26	5,26	5,26	5,26	5,26
Leather products	80,75	61,51	42,26	21,13	1,89	1,89	1,89	1,89	1,89	1,89
Wood products	80,13	60,90	42,95	25,64	10,90	10,26	10,26	10,26	10,26	10,26
Paper products and	80,13	60,90	42,95	25,64	10,90	10,26	10,26	10,26	10,26	10,26
Chemical, rubber and	86,67	73,33	60,00	46,67	33,33	33,33	33,33	33,33	33,33	33,33
Other mineral products	81,22	62,45	45,20	27,96	11,22	10,71	10,71	10,20	10,20	10,20
Ferrous metals	81,22	62,45	45,20	27,96	11,22	10,71	10,71	10,20	10,20	10,20
Other metals	81,22	62,45	45,20	27,96	11,22	10,71	10,71	10,20	10,20	10,20
Metal products	81,22	62,45	45,20	27,96	11,22	10,71	10,71	10,20	10,20	10,20
Motor vehicles and	81,95	63,90	48,77	34,04	20,08	20,08	20,08	20,08	20,08	20,08
Other transport	79,02	64,15	48,66	33,17	18,29	18,29	18,29	18,29	18,29	18,29
Electronic equipment	76,04	52,07	35,32	21,26	7,21	7,21	7,21	7,21	7,21	7,21
Other machinery and	80,00	61,10	46,59	34,29	23,08	23,08	23,08	23,08	23,08	23,08
Other Manufactures	80,00	61,10	46,59	34,29	23,08	23,08	23,08	23,08	23,08	23,08
Water	80,00	61,10	46,59	34,29	23,08	23,08	23,08	23,08	23,08	23,08
services and	90,00	80,00	65,07	50,00	50,00	50,00	50,00	50,00	50,00	50,00

Note: [1] Data source: Wang (2002).

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