GREDI

Groupe de Recherche en Économie
et Développement International

Cahier de Recherche / Working Paper
10-11

Economic Growth, Energy demand and Atmospheric Pollution:

Challenges and Opportunities for China in the future 30 years

Jie HE

David ROLAND-HOLST

UNIVERSITÉ DE SHERBROOKE

Economic Growth, Energy demand and Atmospheric Pollution: Challenges and Opportunities for China in the future 30 years

Jie He
Département d'Économique and GREDI
Université de Sherbrooke
Jie.He@USherbrooke.ca

David Roland-Holst
Mills College, UC Berkeley, and RDRC
dwrh@are.berkeley.edu

(March 15th 2010)

ABSTRACT

This paper uses a dynamic CGE model, calibrated to detailed Chinese emissions data, to assess two important questions. What can we reasonably expect Chinese emissions trends to look like over the next three 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, without further effective emission control measures, China's economic growth over the next two decades will contribute significantly to SO_2 emission problems, in which the emission firstly increase from the rapid expansion of the transportation service sectors until 2018, then from the heavy industrialization process after 2018. With the potential technical progress, the emission burden will be centralized back to two energy sectors: electricity generation and petrol and coke refining during these two periods. 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.

1. Introduction

China's growth has set new standards for a dynamic economy, in Asia or anywhere else. Although many reactions of western commentators and researchers often report the pessimism about China's future, its roaring pace of recovery from the financial crisis and the annual official growth rate of 8.7% in 2009 have put it on course to become the world's second biggest economy behind America. In January 2010, IMF World Economy Outlook Update has revised the projected GDP growth rate of China to 10% for 2010 and 9.7% for 2011. Nobel Price Winner Robert W. Fogel (2010) even projected a steady 8% annual growth rate for China between 2000 to 2040, which leads to a share of 40% of global GDP vs. United States (14%) and the European Union (5%) even China will not have overtaken the United States in per capita wealth.

Put aside at the moment the discussion about the credibility of such optimism, the environmental implications associated to such growth potential should be keenly felt locally and even globally. Since several years, 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.

(Please insert Table 1 about here)

At the same time, the future economic growth in China will also bring consumption mode changes; the increase of demand for transportation service will be an important aspect. If China has becomes since the beginning of 2010 the largest market for automobiles, its significantly low ratio of vehicle possession rate compared to the other countries predicts a fast increase of transportation service demand in the near future. This tendency 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 2 times that of the most industry intensive (Korea).

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 elucidating the linkages between the fast economic growth and pollution trajectories and by searching for the strategies and policies intended to flatten the pollution trajectories arising from China's recent industrial expansion. [1]

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. The important economic events such as China's WTO accession in 2001, the appreciation of Yuan during 2005-2008 are included into the simulation. Considering the important catalyst role of international trade for China's economic growth, we also incorporate a positive growth externality from trade in the model specification. The model is then calibrated to detailed Chinese emissions data, to evaluate two important questions. In light of dramatic industrialization and economic growth, and China's natural resource (especially energy) endowments, what can we reasonably expect emissions trends to look like over the next three decades (2010-2040)? 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 thirty years (1978-2008) 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 30 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 30 times 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 one of the world's most important countries in energy products trade. Statistics show that China's imports and exports of crude oil, coal and natural gas in 2006 totalled 373.96 million standard ton coal equivalents, an increase of 70.2 percent over 2001 and up 11.2 percent annually on average. [2] The implications of its growth and energy demand now encompass global petroleum markets.

(Please insert Figure 1 about here)

Figure 2 illustrates 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 70-75% of her energy production was fueled by the

[1] WDI, 2003.

[2] 26 March 2007, Xinhua News Agency.

domestic coal sector. At the same time, domestic crude oil production remained steady at about 200 MTEC 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.

(Please insert Figure 2 about here)

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.

(Please insert Figure 3 about here)

The trend of 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 Liaohe, are considered to "be nearing depletion and can sustain their current level of production only with additional and sound investments".[3] For example, output from China's largest oil field in Daqing, decreased by 1.7 M tons in 2003.[4] At the same time, the domestic oil consumption has grown steadily since 1980s and recently accelerated with rapid increases in urban automobile ownership.[5] 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 rapid increases in net crude oil import, combining the effects of decreasing exports. China has since 2001 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.[6] According to the statistics published by Chinese government, in 2008, over 54% of China's oil consumption is from import. 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 in the near future, while just over a decade ago China was a net exporter of oil. In the absence of elastic world supply for crude oil, IEA considered China to be the "main driver of global oil demand growth". Based on past experience with energy price spirals, this trend poses the risk of pervasive adjustments in world trade and economic structures.

In addition to the 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 important 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 and most of the governmental initiatives to control SO2 emission increase have been announced as failure. 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.[7] Some studies have

---

[3] Troush, 1999.
[4] "China suffers from high oil prices", *Alexander's Gas & Oil Connections*, vol. 8, issue#5, Thursday, March, 6th, 2003.
[5] See Auffammer et al. (2008) for overviews of these emergent trends.
[6] IEA, 2004.
[7] China's Environment Statistics (1998).

already measured the adverse impact of SO_2 pollution on public health in China, especially as a significant cause of respiratory diseases.[8] Meanwhile, an ever-expanding problem of SO_2-induced acid rain in both south and north China has resulted in rapid undercut in both soil and capital productivity.[9]

(Please insert Figure 4 about here)

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 20 years. Clearly, the most significant positive relationship exists between coal consumption and SO_2, while oil trends exhibit somewhat less important links with SO_2 emission and the natural gas follows a negative correlation with SO2 emission.

3. Modeling Chinese economy

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.[10] The particularity of our production specification is to distinguish energy bundle from other intermediate inputs and allows for continuous substitution between different types of energy.

Because of data constraints, the present model has only one household group, whose 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

[8] Xu et al,1994, Wells, Xu et Johnson, 1994 and World Bank, 1996a, He (2008).
[9] World Bank, 1996b.
[10] The production nesting is explained schematically in Appendix 1.

composition between domestic and the imported goods from different origins.[11] 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. Most goods are assumed to follow the small country assumption. Considering China's increasing share in total world oil import, however, 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.

We assume domestic production demand achieves equality with domestic product supply in equilibrium by adjustment of market price. All factor markets are also supposed to clear in equilibrium. Without detailed data on different skill levels, labor is assumed to be perfectly mobile between sectors, determining a unique equilibrium wage. Capital and land (fixed in the aggregate) are allocated with a CET specification across different sectors according to real rental rate differences. Some natural resources are employed uniquely in specific sectors, such as the mines for coal mining sector, etc. 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.[12]

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. All the tax rates are exogenously specified policy instruments, with initial values calibrated from the baseline SAM.

In the macro closure, we assume the government fiscal balance 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, although some exogenous exchange rate adjustment has been carried out since the middle of 2005.[13]

Expanding trade confers a variety of growth externalities on outward oriented Asian economies, China is not an exception. However, the traditional CGE models can only capture aggregate efficiency gains from removing trade and other price distortions.[14] In our model, inspired by de Melo and Robinson (1990), we go a little further to specify a positive growth

[11] 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.

[12] 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 (1997-2008) and then to independent estimates until 2040.

[13] This assumption is based on the current discussion about the intention of Chinese government to maintain fixed exchange rate regime of RMB in the media, but we always suppose a gradual appreciation trend of RMB with respect to US dollar in the future years. The detailed exchange rate data are from China Statistic Yearbooke (various issues).

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

externality arising from trade (through both exports and imports) and increasing domestic productivity.[15]

4. Modeling environmental consequences

Considering the close link between fossil fuel use and SO_2 emissions, we assume in the model that only fuel combustions in production activities emit SO_2 pollution. The emission rates we use to impute SO2 pollution from energy use in production were obtained by direct estimation from 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 coefficient 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.

(Please insert Table 2 about here)

As the energy data used in these estimates are measured in physical units – TCE (tons of coal equivalence), we further transform this into emission ratios for per monetary units of energy input to map the 1997 SAM. The conversion factors are calculated by dividing the value of total consumption for each type of energy inputs in all the manufacturing sectors in 1997 SAM to their corresponding value in physical unit recorded in the panel database. The conversion factors from physical to monetary units for emission rates for each energy input are given in Table 3.

(Please insert Table 3 about here)

The emission tax, although exists in China since the beginning of 1990, is not accounted for separately in the original SAM. To identify this policy instrument from the total producer tax registrated inSAM, we divide 1997 total SO_2 emission charges by total SO_2 pollution in all the *industrial and service* sectors, calculated from the obtained SO_2 emission rates. This imputation yields a "national-wide average SO_2 levy rate", about 22.22 Yuan per ton of SO_2 emission. Following, we can transform this average SO_2 emission rate into the energy-specific SO_2 emission tax rate by multiplying it by the estimated effluent rates for different energy sources. These energy-specific SO_2 emission tax rates will then be used calculate the SO_2 emission levy revenue from each industrial and service sector for the year 1997 and enable us to identify this part of tax revenue from the total producer tax.

Given the energy-substitutability arrangement in production structure, the energy-specific SO_2 emission tax will enable producers to adapt to the pollution mitigation policies by adjusting their energy structure instead of reducing proportionally their output. We believe this is more consistent with evidence on structural adjustment and energy efficiency growth in the reality.

5. Baseline and Policy Scenario

The main objective of our modeling 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. In this preliminary stage, we work only with the

[15] Detailed specification for the trade externality can be found in He (2005).

baseline dynamic scenario, in which we investigate the potential environmental impacts of China's future 30 year's economic growth. We use the available statistic data on growth rate of GDP and population and labor forces growth from 1997 to reproduce already observed historic growth trends and then calibrate out baseline to median independent estimates, based on the projection of IMF for China's GDP. According to this project, China will firstly growing at a rate over 9% annually till 2020, followed by yearly at the rate of 8.5%, 8.0%, 7.5% and 7.0% for the following 20 years. The detailed population and labor forces growth rates come from the projected UN's POPIN data (see Table 4 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 4.[16] Here, we assume energy inputs enjoy the same productivity growth rate as capital and labor. To take account of Chinese WTO accession period (2001-2010), we added its import tariff and NTB phasing-out and export tax reduction procedures to this baseline.(C.f. Appendix 3) All the other policy instruments are exogenously fixed here. The SO_2 emission levy rate is permitted to vary between 1997 and 2008 to capture the already achieved pollution reductions and then assumed to be unchanged during 2008-2040.[17] The average capital depreciation rate is assumed to be 5%.

(please insert Table 4 about here)

6. Computational Results

The macroeconomic effects, SO_2 emissions changes, and results for energy use obtained from our baseline simulation are listed in Table 5. We first present their variations over the last eight years (1997-2008). Those for the 30 years ahead (2008-2040) are then grouped into six 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 increase by more than 10 times over the next 30 years. At the same time, real disposable income will also increase by a almost 10 times. Total private consumption, parallel to income growth, will also be ten times higher by 2040 with respect to 2008, where the most important increases are in the consumption of service (14.8 times higher) and industrial goods (12.6 times higher).

(please insert Table 5 about here)

Economic Effects

We can identify obvious structural transformation in the simulation. Since the beginning, the share of the aggregate agricultural output will decrease monotonically, its negative average yearly growth rates indicate that absolute production levels in agriculture will contract at an accelerating rate. Industry sector will expand rapidly during all the projected period, with the annual growth rate stays steadily over 10% almost all the time and a fast growth period during 2020-2035. The construction, as the most important growth-promotion sector since 2000, will gradually lose its vitality by showing decreasing annual growth rate during the projected period. Our results also show that China will experience temporary rise of output share of service sector, especially during the period 2008-2020,

[16] 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.

[17] Detailed emission data are from China Environmental Statistical Yearbook and China Statistical Yearbook (various issues).

where the annual growth rate of this sector will overpass that of industry sector. (C.f. Figure 5)

(please insert Figure 5 about here)

Reduction in agriculture production will increase China's dependence on imports food and other agricultural products. This effect is most evident during the 1997-2015 periods, when the absolute Chinese population growth attains its maximal level. Because of WTO adhesion, China will profit most from export and import growth during 2000-2015, with both total export and total import rising over 15% each year. With the consumption structure relatively stable and following parallel movements with income growth, China's production structure changes are driven more by export and import variations, one example is the dramatic in service sector exports, rising by more than 20% each year till 2020. Such a typical companion of dynamic and export-oriented growth can also be observed in the industry sector, whose fast growth period during 2020-2035 should also be explained by the obverse improvement in its export performance.

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 2 sub-periods and the last four. 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, which confirm with the observed tendency from the historical statistics. However, from 2015, the growth rate of total emissions is predicted to be notably higher than its aggregate economic growth counterparts. A parallel situation can also be found for SO_2 emissions from service sector during 2008-2015 and from industry sector during 2015-2030. 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 goes upwards from 2015. This means SO_2 intensity forms an inverted U curve, with the minimum around year 2015.

(please insert Figure 6 about here)

Since these results about the SO_2 emission intensity is contradict more optimistic scenarios, like those more congruent with the Environmental Kuznets Curve, they deserve closer inspection.[18] Figure 7 shows the sectoral distribution of SO_2 emissions. We observe a rapid increase in the share of SO_2 emissions from the service sector during 2008-2018 and a fast re-increase phase for the share of SO_2 emission from industry sector during 2018-2030. Compared with the structural transition described in Figure 5, the changes in sectoral share of emission shown in Figure 7 seem to follow very tight correlation with the changes in the sector output shares. However, we can also see that the changes in output shares are not enough to explain the shifts in SO_2 emissions: both the increasing trend in the emission share of service sector during 2008-2018 and that of the industry sector after 2018 are more significant than the variations in sector output share during the corresponding period. Thus we still need to look more closely at sectoral emissions to understand the SO2 trends.

(Please insert Figure 7 about here)

Besides the changes in sector output shares mentioned above, another cause for this trend in SO_2 emission intensity can be identified in detailed results on energy consumption. Table 5 reveals a general slower growth rate in coal consumption with respect to the other

[18] A good general treatment of the EKC can be found in Stern (2004) and Dinda (2004).

three 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 this period. After 2015, by contrast, we observe crude oil and petrol and coke consumption rising much faster than all the other energy sources. Since petroleum products are the second most important source of SO_2 emission, we believe this is responsible for reversing the trend in aggregate SO_2 emission intensity.

(Please insert Figure 8 about here)

Comparison of Figure 8 with the sectoral emission share changes in Figure 7 provides useful insight into the process in question. During the early phase of growth (1997-2015), industry sector dominates GDP. Its significant pollution efficiency gains seem to be big enough to overcome the SO_2 emission increase trend contributed by the increase in pollution intensity of service sector. During the latter phase, as both the output share and the pollution intensity of industry sector rise rapidly, their contribution dominates largely the pollution decrease contributed by the service sector, we therefore observe the fast emission intensity increases. Agriculture experiences increasing pollution intensity too, but its GDP share is declining faster, therefore its contribution stays marginal in the total account.

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, SO_2 emission intensity is a combined result of emission from three fuel sources, coal, crude oil, and petrol and coke. (C.f. Table 3)

(Please insert Figure 9 about here)

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 1997-2015. Unfortunately, the benefits of declining coal intensity are eventually overtaken by aggregate growth, with its attendant growth of other pollution intensive energy sources.

If we agree with Grossman (1995), who considered industrial pollution as a "joint-product" of conventional output, we can use Divisia Index decomposition to decompose the SO_2 emission results of our simulation into the contribution from its three determinants: the scale, composition and technical characteristics of China's economy. 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

$$SO_{2_i} = \sum_f \left(\underbrace{\left(\frac{\phi_f \times X_{f,i}}{X_i}\right)}_{Technique\ effect} \times \underbrace{\left(\frac{X_i}{\sum_i X_i}\right)}_{Composition\ effect} \times \underbrace{\sum_i X_i}_{Scale\ effect} \right). \quad (1)$$

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 (1) to show how the change in SO_2 emission between period t and the initial period (0) is determined component variations as

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

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

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

$$+residuals\qquad(2)$$

(Please insert Table 6 about here)

This Divisia decomposition method has the advantage of revealing very detailed determinants of the three emission components, which will enable us to identify the exact industry and service industries as the most important sources for SO_2 emission changes. The aggregated decomposition results for our baseline scenario are listed in Table 6. To further clarify the SO_2 emission trends, we divided the 1997-2040 period into four sub-periods, 1997-2008, 2008-2018 and 2018-2030 and 2030-2040.[19] As expected, given the projected high economic growth rate, the scale effect contributes always positively to the total SO_2 emission during all the four sub-periods. Structurally speaking, the industry sector contributes the biggest part of SO_2 emission growth, which will be over 70% during 1997-2008 and 2008-2018 and over 95% for the last two sub-periods. The other important part of emission growth comes from the service sector. After contributing about 20% of pollution increase in 1997-2008, its most significant increase in the SO_2 emission contribution is found for the sub-period 2008-2018, about 30% of the SO_2 emission during this sub-period can be explained by this sector. During 2018-2030, although the absolute value of its SO2 emission remains the same, its proportional contribution will decline rapidly to 3% and during the last sub-period, its contribution to the total SO2 emission will become negative.

(Please insert Tables 7-9 about here)

Table 7-9 gives the detailed decomposition results for the 5 energy industries, the 25 industrial manufacture industries and the 11 service industries. These tables reveal more details about the contribution of the each industry in total SO_2 emission.[20]

Coherent to Table 6, the table 7 reveals, from a structural perspective, an interesting commonality between the four sub-periods. This is the concentration of SO_2 emission into the

[19] The choice about how to cut the sub-periods is based on the dynamic evolution of the projected SO_2 emissions.
[20] The decomposition in Table 7-9 takes the SO_2 emission from the corresponding sector as 100% but not the whole Chinese economy as 100%. In this case, a positive number recorded in the "composition effect column" means a faster growth of the corresponding industry with respect to the sector, but not with respect to the whole Chinese economy. The purpose of doing this is to avoid the strong influence from the dramatic fast growth of some energy industries, which very often causes negative composition effect contribution of other industries, even if these sectors will also experience faster than average growth with respect to their corresponding aggregate sector.

energy sector, especially into the electricity generation and petrol and coke industries. This can be read from either the large positive numbers recorded in composition effects for the energy-related sector/industries, or simply the big numbers listed in the last column of Table 6 and 7. This finding suggests that with economic growth, China will gradually reduce dependence on raw energy such as coal, and substitute it with cleaner intermediate energy, especially oil products and electricity. This process actually contributes to the negative entries in the technical effect columns of the fours sub-periods, which can be systematically founded through Table 6-9.

Beside the technical effect contributed principally by the substitution between energies of different SO_2 effluent rates, the changes in the structure of manufacture and service sectors are also important factor to explain the variation of China's SO_2 emission changes.

For the 25 manufacture industries (c.f. Table 8), two categories of industries evolve in opposite tendency. Most of the labor-intensive light industries, such as textile, wearing apparel, leather products and electronic equipments industries, have realised faster development during 1997-2008. Given this sub-periods covers the most important phase of China's WTO accession (2000-2010), the faster development of these sectors (illustrated by the positive numbers recorded in the composition effect column) should be explained by the realisation of more thorough specialisation under trade liberalisation. During the period 2008-2018, the light industries as textile and wearing apparel will start to lose their comparative advantage, although some newly emergent labour-intensive sectors, especially electronic equipment, instead continue their important expansion.

China's heavy industries (such as Chemical products, other mineral products, ferrous metals, other metal and metal products, etc.) are projected to experience faster expansion only after 2018, this can be seen from the large positive numbers recorded for these industries in the composition effect columns. With income growth and improvement of live standards, some luxury durable product sectors, such as motor vehicles and other transportation equipment, also show some expansion of their GDP share because of positive Engel effects. This means the transformation of China's industrial structure from light-industry dominated one to heavy-industry dominated one will take place during the period 2018-2040. This also gives intuitive explanation for the significant increase in SO_2 emission during this period (c.v. Table 6): all these heavy industries are energy-intensive, the expansion of their production activities will lead SO_2 emission to increase significantly. Another interesting details revealed by the decomposition results for manufacture industries is the some heavy industries seems to have less persistent expansion trends than others (ferrous metals and other metal vs. chemical product and other mineral product). This might be explained by the natural resource endowment situation of China.

Table 9 reports the detailed decomposition results for the 11 service industries. From a structural point of view, the three sectors that will enjoy higher-than-average growth rate are the three transport-related industries (Land, Sea and Air transport). This is revealed by their relatively larger positive numbers recorded in the composition effect columns.[21] Dynamically, our results also predicts that it will be sea transport and air transport sector to firstly enjoy faster development during 2008-2018, which should be explained by the fast development of international trade and high merchandise mobility around the world. After 2018, it will be the

[21] A positive number associated to the composition effect means the corresponding industries (sectors) experience during the analysed sub-period an average annual growth rate higher than the average growth rate of the whole sector that it belongs to. Analogically, a negative number associated to the composition effect means the corresponding industries (sectors) experience during the analysed sub-period an average annual growth rate slower than the average growth rate of the whole sector that it belongs to.

land transport industry to realise significantly higher development speed, which signify the increasing demand for the road transport, this results are coherent with the high vitality expressed by the motor vehicle industry during the same period. (c.f. Table 7)

In one world, if our simulation predicts an ever-increasing trend for total SO_2 emission, this is a final result of the force-contrast of three factors. The scale effect, contributing proportionally to the increase of SO_2 emission, will be amplified by the composition effect, whose impact on China's environment until 2040 should be in general negative, owing to the heavy industrialisation processes and the fast development transport-related service. Although we can expect some pollution reduction contribution from the technique effect, owing to the improvement of energy use efficiency and substitution of the polluting energies by less polluting ones. Till 2040, the domination of the scale and composition effects over the technique effect will be maintained. [22]

7. 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 dynamic CGE model, we examined the relationships between economic growth, structural transformation, energy use, and an important category of industrial pollution, 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 could give rise to very significant SO_2 emission growth in the future 30 years. Our simulations show that sustained growth and heavy industrialisation process in the next 30 years will induce significant structural transformation in the Chinese economy. On one hand, we see the decline in the importance of the labour-intensive sectors, accompanied by an increase 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 especially those related to transport service.

This structural transition will deteriorate the environmental conditions for China. However at the same time, we also observe a general tendency of substitution away from the most polluting raw energy sources. In this process, coal can be significantly displaced by relatively cleaner intermediate energies such as electricity, oil products and natural gas in manufacturing. SO_2 emissions re-concentrate into intermediate energy sectors (electricity generation and petrol and coke sectors) from the other manufacturing and services. This actually confers an administrative benefit for emission control since monitoring and de-sulphurization efforts can be concentrated 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 could reduce the total SO2 emission from the whole economy by 50% before 2018 and by almost the same percentage point after.

[22] Due to lack of credible data, the modeling used in this paper does not include the potential improvement of the SO_2 effluent rate for various type of energy use. We should expect a larger SO2 emission reduction contribution from technical effect if such a possibility is included into the model.

After 2018, an important emergent emission source is transport services, making this another primary target for 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 vehicle technologies in China.

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 and the intention to replace the coal by less polluting oil-based energy will probably further accelerate already rapid growth of China's oil imports. From Figure 10, it is apparent that, due to the rapid increase in total oil consumption, especially for the period 2018-2040, the crude import ratio in total consumption will reach about 100%. Since we assumed in the model that China could influence the oil terms-of-trade, we also expected almost 66%'s increase in the oil price. In light of global oil supply constraints, China's oil needs will unavoidably influence world prices, adversely affecting export competitiveness and complicating multilateral relations.[23]

(Please insert Figures 10-11 about here)

Extensions of the present work are numerous. Here we only examine a single baseline scenario, without 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 was used to calibrate the model, and it is certainly not reasonable to expect government passivity in the face of adverse energy markets or environmental trends. 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. The primary objective of this paper is to elucidate the risks facing policy makers and the urgent need for evidence based research support to help China adapt to the domestic and global challenges arising from its growth momentum.

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

REFERENCE

Ancreoni, J. and A. Levinson (2000) “The Simple Analytics of the Environmental Kuznets Curve,” *Journal of Public Economics.*

Ang, B.W. and G. Pandiyan (1997). Decomposition of energy-induced CO_2 emissions in manufacturing, *Energy Economics*, Vol. 19, pp363-374.

Armington, Paul (1969), “A Theory of Demand for Products Distinguished by Place of Production,” *IMF Staff Papers*, Vol. 16, pp. 159-178.

Aufhammer, M. and R.T. Carson and T. Garin-Munoz (2004), Forecasting The Path of China's CO2 Emissions Using Province Level Information. *Journal of Environmental Economics and Management*. 47(1): 47-62.

Beghin, J., B. Bowland, S. Déssus, D. Roland-Holst, (1999). Trade, Environment, and Public Health in Chile: Evidence from an Economy-wide Model, in P.G. Fredriksson eds. *Trade, Global Policy, and the Environment*, World Bank, 1999, pp35-54.

Beghin, J., S. Dessus, D. Roland-Holst and D. van der Mensbrugghe (1996). *General Equilibrium Modelling of Trade and the Environment*, Technical paper, No. 116, OECD.

Beghin, J., S. Dessus, D. Roland-Holst and D. van der Mensbrugghe (2002). Trade Integration, Environmental Degradation, and Public Health in Chile: Assessing the Linkage, Environment and Development Economics, Vol. 7, Part 2, pp241-267.

Beghin, J., S. Dessus, D. Roland-Holst and D. van der Mensbrugghe (1997). The Trade and Environment Nexus in Mexican Agriculture: A Genral Equilibrium Analysis, *Agricultural Economics*, Vol. 17, pp115-131.

Beijing Environment, Science and Technology update, 14, June, 2002.

Cao, D., J. Yang and C. Ge (1999). SO_2 Charge and Taxation Policies in China: Experiment and Reform, in (OECD eds.) *Environmental Taxes: Recent Developments in China dn OECD Countries,* OECD, 1999, pp233-257.

De Melo, J., and S. Robinson (1990). *Productivity and Externalities: Models of Export-led Growth,* Mémo. 90.10, University of Geneva.

De Melo, Jaime, and Sherman Robinson (1989), “Product Differentiation and the Treatment of Foreign Trade in Computable General Equilibrium Models of Small Economies,” *Journal of International Economics*, Vol. 27, pp. 47-67.

Deaton, Angus, and John Muellbauer (1980), *Economics and Consumer Behaviour*, Cambridge University Press, Cambridge, UK.

Derviş, Kemal, Jaime de Melo and Sherman Robinson (1982), *General equilibrium models for development policy*, A World Bank Research Publication, Cambridge University Press, New York, NY.

Dessus, S. and M. Bussolo (1998). Is There a Trade-off Between Trade Liberalization and Pollution Abatement? A Computable General Equilibrium Assessment Applied to Costa Rica, *Journal of Policy Modeling*, Vol. 20(1). pp.11-31.

Dessus, S., D. Roland-Holst and D. van der Mensbrugghe (1994). *Input-based Pollution Esimates for Environmental Assessment in Developing Countries*, Technical papers, No. 101, OECD.

Francois, Joseph and Kenneth Reinert (1997), *Applied Methods for Trade Policy Analysis : A Handbook*, Cambridge University Press, New York, NY.

He, J (2005). Estimation on Economic Cost of China's New De-sulfur Policy During Her Gradual Accession to WTO: The Case of Industrial SO2 Emission. *China Economic Review*, 16(4): 364-403, 2005.

He, J. (2008). Industrialisation, Environment and Health : the Impacts of Industrial SO2 Emission on Public Health in China. *Chinese Journal of Popultion, Resources and Environment*.Vol. 6, no. 1, p. 14-24.

Hertel, Thomas W., editor (1997), *Global Trade Analysis: Modeling and Applications*, Cambridge University Press, New York, NY.

Howe, Howard (1975), “Development of the Extended Linear Expenditure System from Simple Savings Assumptions,” *European Economic Review*, Vol. 6, pp. 305-310.

Lawrence Berkeley National Laborarory (2001). *China Energy Databook,.5.0*, Berkeley, 2001.

Lee, H. and D. Roland-Holst (1997). The Environment and Welfare Implications of Trade and Tax Policy, *Journal of Development Economics*, Vol. 52, pp.65-82.

Lluch, Constantino (1973), “The Extended Linear Expenditure System,” *European Economic Review*, Vol. 4, pp. 21-32.

Qiang, J. and K. Zhang (1998). China’s Desulfurization Potential, *Energy Policy*, Vol. 26, No. 4, pp345-351.

Roland-Holst, D. and D. Van der Mensbrugghe (2002). *Prototype Specification for a Real Computable General Equilibrium Model of China*, Date of current version: Oct. 21, 2002.

SEPA, (1998-2000). *China's Environmental Statistic Yearbook*, Beijing.

Shen, L. (1997). *Speech make at the Clean Coal Initiative Conference*, World Bank.

Shoven, John B. and John Whalley (1984), "Applied General-Equilibrium Models of Taxation and International Trade: An Introduction and Survey," *Journal of Economic Literature*, Vol. XXII(3), September, pp. 1007-51.

Shoven, John B. and John Whalley (1992), *Applying General Equilibrium*, Cambridge Surveys of Economic Literature, Cambridge University Press, New York, NY.

Van der Mensbrugghe, D., D. Roland-Holst, S. Dessus, and J. Beghin (1998). The Interface Between Growth, Trade, Pollution and Natural Resource Use in Chile: Evidence from an Economy-wide Model, *Agricultrual Economics*, Vol. 19, pp 87-97.

Wang (1996). Taxation and Environment in China: Practice and Perspectives, in OECD ed. *Environemental Tax : Recent Development in China and OECD Countries*.

Wang, Z. (2002). The Impact of China's WTO accession on Patterns of World Trade, *Journal of Policy Modeling*, Vol. 5298, pp1-42.

World Bank (1996). China : *Chongqing Industry pollution control and reform project,* Staff Appraisal Report, Washington DC.

Xu, X., B. L. Li, et H. Y. Huang (1996). *Air Pollution and Unscheduled Hospital outpatient and Emergency Room Visits*. *Environmental Health Prospective*.

Xu, X., J. Gao, D. W. Dockery et Y. Chen (1994). *Air Pollution and Daily Mortality in Residential Area of Beijing*, China. *Archives of Environmental Health*, 49(4). pp216-222.

Yang, H-Y, (2001). Trade Liberalisation and Pollution: A General Equilibrium Analysis of Carbon Dioxide Emissions in Taiwan, *Economic Modelling*, Vol. 18, pp. 435-454.

Yang, J. and S. Benkovic (2002). The Feasibility of Using Cap and Trade to Achieve Sulfur Dioxide Reductions in China, *The Sinosphere Journal*, Vol. 4, Issue 1, July, 2002, pp10-14.

Table 1. Comparison between several indicators beween countries

Country	GDPPC (2000 constant US dollar)	Steel production (Annual Kg per capita)	Vehicles (per 1,000 people)	Electricity consumption (Kwh per capita)	Energy use (kg of oil equivalent per capita)
China	1612	322	21	2041	1433
Korea	14469	1003	311	8063	4483
Japan	39911	910	586	8220	4129
France	24019	324	595	7813	4444
United State	37757	330	808	13582	7778

Note: 1. Data compiled by the authors according to the available statistics in World Development Indicator, 2009 and World Steel association.

2. The data are in general of the year 2006, except the vehicle per 1000 persons, which are of 2004.

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).

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).

TABLE 4. IMPORTANT EXOGENOUS VARIABLES IN THE BASELINE SCENARIO

Exogenous variables	Year	growth rate (real)	Endogenous variables	Year	growth rate
GDP (percent)	1997	9.299	**Productivity growth path to meet the expected economic growth during 1997-2040 (reference to preceding year)**	1997	0.00
	1998	7.798		1998	2.19
	1999	7.6		1999	3.54
	2000	8.403		2000	4.32
	2001	8.308		2001	3.71
	2002	9.104		2002	4.69
	2003	10.003		2003	5.69
	2004	10.105		2004	5.69
	2005	10.403		2005	6.29
	2006	11.606		2006	8.31
	2007	13.012		2007	9.44
	2008	9.007		2008	5.93
	2009	8.504		2009	5.57
	2010	9.028		2010	6.34
	2011	9.733		2011	7.58
	2012	9.838		2012	7.39
	2013	9.767		2013	7.45
	2014	9.509		2014	7.43
	2015-2020	9.0		2015	6.88
	2020-2025	8.5		2016	7.48
	2025-2030	8.0		2017	7.17
	2030-2035	7.5		2018	7.62
	2035-2040	7.0		2019	7.47
Population (1/1000)	1995-2000	0.90		2020	7.53
	2000-2005	0.70		2021	7.06
	2005-2010	0.63		2022	6.98
	2010-2015	0.61		2023	6.94
	2015-2020	0.50		2024	6.90
	2020-2025	0.31		2025	6.84
	2025-2030	0.13		2026	6.82
	2030-2035	-0.00		2027	6.55
	2035-2040	-0.10		2028	6.49
Labor Force (Percent)	1995-2000	1.24		2029	6.42
	2000-2005	1.57		2030	6.35
	2005-2010	1.04		2031	6.69
	2010-2015	0.51		2032	6.19
	2015-2020	-0.04		2033	6.11
	2020-2025	0.01		2034	6.01
	2025-2030	-0.27		2035	5.89
	2030-2035	-0.67		2036	6.47
	2035-2040	-0.74		2037	5.48
Exchange rate (PPP)	1997	8.28		2038	5.34
	1998	8.28		2039	5.16
	1999	8.28		2040	4.95
	2000	8.28	**Total SO_2 emission actually observed in the historical statistics (million tons)**	1997	1362.6293
	2001	8.28		1998	1600
	2002	8.28		1999	1460.0949
	2003	8.28		2000	1615.3200
	2004	8.28		2001	1566
	2005	8.19		2002	1561.9806
	2006	7.97		2003	1791.562
	2007	7.61		2004	1891.4
	2008	6.95		2005	2168.4
	2009	6.84		2006	2234.8
	2010	6.82		2007	2140.0
	2011	6.83		2008	1996.3
	2012	6.86			
	2013	6.87			
	2014	6.75	2015-2040		Annual appreciation rate of 2%

Note about the data sources: the projected GDP growth rates come from IMF-World Economy Outlook. The projected population and labor force growth rates come from UN POPIN. The exchange rate variations during 1997-2009 comes from China Statistic Yearbook and the total SO2 emission from 1997-2008 comes from the China Environmental Yearbook. The predicted annual appreciation rate for RMB is based on the discussion found in media.

Table 5. Macro Variables and Emission

	Real Value									Annual average growth rate						
Macroeconomic factors	**Unit**	**1997**	**2010**	**2015**	**2020**	**2025**	**2030**	**2035**	**2040**	**1997-08**	**2008-15**	**2015-20**	**2020-25**	**2025-30**	**2030-35**	**2035-40**
Real GDP	10^9 US$	854.69	2335.43	4363.49	6717.22	10111.61	14859.98	21328.32	29913.31	9.57	9.34	9.01	8.52	8.00	7.49	7.00
Real GDPPC	US$	691.35	1742.82	3119.32	4683.66	6942.17	10136.13	14548.23	20302.42	8.77	8.67	8.47	8.19	7.86	7.49	6.89
Aggregate output	10^9 US$	2280.77	6541.75	13438.81	22376.84	38022.52	63569.07	101099.65	154954.57	10.05	10.83	10.74	11.19	10.83	9.72	8.92
Agriculture output	10^9 US$	263.03	292.02	258.84	216.98	170.56	118.87	64.78	27.33	0.96	-1.71	-3.47	-4.70	-6.97	-11.43	-15.85
Industry	10^9 US$	1337.69	4245.59	8964.23	14622.40	26378.32	49336.37	84725.74	135179.22	11.07	11.27	10.28	12.52	13.34	11.42	9.79
Construction	10^9 US$	210.22	696.52	1333.49	2013.29	2887.07	3968.12	5284.43	6794.23	11.51	9.72	8.59	7.48	6.57	5.90	5.15
Service	110 US$	469.83	1307.62	2882.26	5524.18	8586.59	10145.72	11024.70	12953.79	9.75	11.95	13.90	9.22	3.39	1.68	3.28
Private Consumption	10^9 US$	2290.10	6617.90	13171.74	20624.48	30301.27	42819.31	59498.76	81995.63	10.13	10.33	9.38	8.00	7.16	6.80	6.62
Agriculture	10^9 US$	265.32	427.06	624.63	819.27	1076.81	1426.96	1931.03	2655.92	4.42	5.58	5.57	5.62	5.79	6.24	6.58
Industry	10^9 US$	1342.87	4233.25	8705.13	13693.03	19954.83	28070.47	38860.99	53206.11	11.00	10.85	9.48	7.82	7.06	6.72	6.49
Construction	10^9 US$	211.19	703.65	1353.15	2053.87	2968.09	4138.06	5663.71	7622.90	11.56	9.79	8.70	7.64	6.87	6.48	6.12
Service	111 US$	470.73	1253.93	2488.83	4058.31	6301.54	9183.82	13043.03	18510.69	9.32	10.29	10.27	9.20	7.82	7.27	7.25
Investment	10^9 US$	310.00	1048.70	2014.96	3050.57	4395.18	6119.89	8376.54	11274.49	11.72	9.78	8.65	7.58	6.84	6.48	6.12
Export	10^9 US$	235.93	1108.40	2919.92	5658.61	10905.91	20456.79	35866.92	59674.95	15.10	14.84	14.15	14.02	13.41	11.88	10.72
Agriculture	10^9 US$	6.15	0.31	0.04	0.01	0.00	0.00	0.00	0.00	-23.78	-26.62	-24.42	-22.26	-25.47	-34.56	-41.77
Industry	10^9 US$	209.51	993.51	2429.65	4125.49	8389.02	18417.51	35024.06	59271.84	15.20	13.63	11.17	15.25	17.03	13.72	11.10
Construction	10^9 US$	0.55	1.39	2.07	2.28	2.26	1.88	1.31	0.86	8.73	5.89	1.93	-0.17	-3.65	-6.89	-8.14
Service	10^9 US$	19.72	113.19	488.16	1530.83	2514.62	2037.40	841.54	402.26	17.22	23.22	25.68	10.44	-4.12	-16.21	-13.72
Import	10^9 US$	245.26	1396.52	3773.96	7133.56	12935.13	22889.49	39073.77	64567.11	17.13	15.26	13.58	12.64	12.09	11.29	10.57
Agriculture	10^9 US$	8.44	237.31	895.85	1769.57	3054.44	4926.22	7696.06	11497.19	35.43	20.90	14.58	11.54	10.03	9.33	8.36
Industry	10^9 US$	214.69	1080.69	2676.02	4941.01	8989.46	15980.93	26691.72	42299.86	15.83	13.83	13.05	12.72	12.20	10.80	9.65
Construction	10^9 US$	1.52	8.80	23.42	48.56	100.74	229.25	581.14	1468.91	17.29	15.01	15.70	15.71	17.88	20.45	20.38
Service	10^9 US$	20.62	69.73	178.66	374.42	790.49	1753.09	4104.85	9301.16	11.71	14.39	15.95	16.12	17.27	18.55	17.77
Real disposable income	10^9 US$	750.34	2263.74	4409.48	6428.80	9021.20	12558.65	17611.25	24332.65	10.56	9.99	7.83	7.01	6.84	7.00	6.68
Per capita	US$	606.95	1689.33	3152.20	4482.56	6193.54	8566.36	12012.79	16514.78	9.75	9.32	7.30	6.68	6.70	7.00	6.57

Table 5. Macro variables and emission (continue)

	Real Value									Annual average growth rate						
Emission and energy use	**Unit**	1997	2008	2015	2020	2025	2030	2035	2040	**1997-08**	**2008-15**	**2015-20**	**2020-25**	**2025-30**	**2030-35**	**2035-40**
Total SO2 emission	10^3 tons	8259.72	12311.72	21939.49	46569.19	120268.63	243134.05	395179.46	573654.17	3.70	8.60	16.25	20.90	15.12	10.20	7.74
Agriculture	10^3 tons	198.07	388.87	461.26	471.36	439.98	348.25	210.82	101.15	6.32	2.47	0.43	-1.37	-4.57	-9.55	-13.66
Industry	10^3 tons	7359.47	10305.21	17261.89	35597.79	103729.37	228803.86	383880.85	561670.16	3.11	7.65	15.58	23.85	17.14	10.90	7.91
Construction	10^3 tons	31.29	66.80	105.25	143.24	198.42	274.18	374.63	493.99	7.14	6.71	6.36	6.73	6.68	6.44	5.69
Service	10^3 tons	670.89	1550.85	4111.11	10356.79	15900.86	13707.76	10713.16	11388.87	7.92	14.94	20.30	8.95	-2.92	-4.81	1.23
Total coal input	10^6 TCE	333.29	381.16	532.71	744.90	1002.11	922.17	727.25	653.05	1.23	4.90	6.94	6.11	-1.65	-4.64	-2.13
Agriculture	10^6 TCE	5.57	9.35	9.03	7.52	5.75	4.11	2.19	0.84	4.82	-0.48	-3.61	-5.22	-6.50	-11.82	-17.41
Industry	10^6 TCE	315.69	360.50	510.01	722.15	979.28	898.50	702.88	627.83	1.21	5.08	7.20	6.28	-1.71	-4.79	-2.23
Construction	10^6 TCE	1.14	1.72	2.24	2.47	2.78	3.40	4.24	5.12	3.81	3.85	2.00	2.42	4.11	4.49	3.83
Service	10^6 TCE	10.90	9.60	11.43	12.77	14.30	16.16	17.94	19.27	-1.15	2.53	2.24	2.29	2.48	2.12	1.44
Total oil input	10^6 TCE	81.52	167.16	358.25	1112.62	4425.65	10837.69	18554.26	26900.17	6.75	11.51	25.44	31.80	19.62	11.35	7.71
Agriculture	10^6 TCE	0.06	0.10	0.09	0.08	0.07	0.05	0.03	0.01	4.74	-0.13	-2.50	-3.64	-5.54	-11.12	-17.13
Industry	10^6 TCE	81.34	166.94	358.04	1112.42	4425.45	10837.48	18554.06	26899.96	6.75	11.52	25.45	31.81	19.62	11.35	7.71
Construction	10^6 TCE	0.01	0.02	0.02	0.03	0.03	0.04	0.05	0.06	6.84	2.43	1.74	3.10	4.70	5.31	4.91
Service	10^6 TCE	0.11	0.10	0.09	0.09	0.10	0.11	0.13	0.14	-0.86	-1.47	-0.63	1.56	3.00	2.77	1.67
Total petrol&coke input	10^6 TCE	134.59	360.49	842.42	2121.76	5565.49	11321.97	18834.51	28090.12	9.37	12.89	20.29	21.27	15.26	10.71	8.32
Agriculture	10^6 TCE	9.44	21.36	29.00	32.69	32.78	26.73	16.71	8.39	7.71	4.47	2.43	0.05	-4.00	-8.97	-12.87
Industry	10^6 TCE	77.93	201.02	425.12	1088.48	3987.35	9961.56	17772.09	26962.14	9.00	11.29	20.69	29.65	20.10	12.27	8.69
Construction	10^6 TCE	1.03	3.47	6.30	9.61	14.44	20.75	29.09	39.20	11.65	8.92	8.80	8.50	7.51	6.99	6.15
Service	10^6 TCE	46.19	134.64	382.00	990.97	1530.92	1312.93	1016.62	1080.39	10.21	16.06	21.00	9.09	-3.03	-4.99	1.22
Total gas input	10^6 TCE	21.54	44.25	61.88	78.19	95.52	88.03	72.06	64.57	6.76	4.91	4.79	4.09	-1.62	-3.92	-2.17
Agriculture	10^6 TCE	0.01	0.03	0.03	0.03	0.03	0.02	0.01	0.00	7.49	2.59	-1.24	-3.89	-6.32	-12.42	-18.71
Industry	10^6 TCE	21.00	43.23	60.55	76.69	93.83	86.06	69.81	62.09	6.79	4.93	4.84	4.12	-1.71	-4.10	-2.32
Construction	10^6 TCE	0.14	0.40	0.58	0.68	0.78	0.95	1.15	1.33	9.92	5.25	3.17	2.97	4.00	3.91	2.93
Service	10^6 TCE	0.39	0.58	0.72	0.80	0.89	1.00	1.09	1.14	3.67	2.95	2.16	2.12	2.46	1.79	0.82
Total electricity	10^6 Kwh	1.00	2.79	5.32	8.54	12.50	12.62	10.94	10.49	9.77	9.67	9.92	7.93	0.18	-2.81	-0.84
Agriculture	10^6 Kwh	0.06	0.15	0.20	0.21	0.19	0.14	0.09	0.04	8.15	4.06	0.88	-1.82	-5.45	-9.65	-12.76
Industry	10^6 Kwh	0.84	2.40	4.69	7.69	11.42	11.35	9.54	8.93	9.98	10.05	10.38	8.24	-0.12	-3.42	-1.31
Construction	10^6 Kwh	0.02	0.07	0.13	0.20	0.28	0.37	0.46	0.57	13.26	10.06	8.53	7.20	5.73	4.62	4.11
Service	10^6 Kwh	0.08	0.17	0.30	0.45	0.62	0.76	0.85	0.95	7.59	8.38	8.16	6.65	4.08	2.46	2.11

Table 6. Divisia Decomposition results (aggregated results)

	Scale effect	Composition effect	Technique Effect	residuals	TOTAL
			2008 vs. 1997		
Agriculture	295.93	-242.67	137.49	0.04	190.80
Industry	9161.95	1546.35	-7745.92	-16.64	2945.73
Energy	*5621.98*	*1222.70*	*-5051.35*	*-10.60*	*1782.73*
Manufacture	*3539.97*	*323.65*	*-2694.57*	*-6.04*	*1163.00*
Construction	49.33	6.75	-20.51	-0.06	35.51
Service	1079.31	127.68	-329.10	2.08	879.96
Total	10586.53	1438.11	-7958.05	-14.59	4052.00
			2018 vs. 2008		
Agriculture	431.76	-511.82	161.68	0.19	81.81
Industry	16540.93	8032.58	-10149.58	-16.82	14407.10
Energy	*11565.07*	*8808.33*	*-7841.50*	*-15.18*	*12516.72*
Manufacture	*4975.86*	*-775.75*	*-2308.09*	*-1.64*	*1890.38*
Construction	95.45	-11.48	-24.62	0.05	59.39
Service	3698.14	3146.78	-788.71	1.12	6057.33
Total	20766.27	10656.06	-10801.23	-15.46	20605.63
			2030 vs. 2018		
Agriculture	501.41	-819.33	195.26	0.23	-122.43
Industry	104429.05	131035.09	-31311.71	-60.88	204091.55
Energy	*96075.17*	*135907.85*	*-29534.98*	*-58.89*	*202389.15*
Manufacture	*8353.88*	*-4872.76*	*-1776.73*	*-1.99*	*1702.40*
Construction	238.69	-78.38	-12.60	0.28	147.99
Service	12909.42	-5112.86	-1699.83	2.85	6099.58
Total	118078.58	125024.52	-32828.88	-57.52	210216.70
			2040 vs. 2030		
Agriculture	173.18	-505.49	85.21	0.01	-247.10
Industry	327808.30	105776.56	-100716.46	-2.10	332866.29
Energy	*320315.39*	*111191.78*	*-100396.99*	*-2.07*	*331108.11*
Manufacture	*7492.90*	*-5415.22*	*-319.47*	*-0.03*	*1758.18*
Construction	332.67	-131.88	18.99	0.04	219.81
Service	10585.17	-12340.56	-563.73	0.23	-2318.89
Total	338899.32	92798.62	-101175.99	-1.83	330520.12

Table 7. Divisia Decomposition results (Disaggregated 25 manufacture industries)

	Scale effect	Composition effect	Technique Effect	residuals	TOTAL	Scale effect	Composition effect	Technique Effect	residuals	TOTAL
	2008 vs. 1997					2018 vs. 2008				
Mining	57.68	-1.70	-34.78	-0.16	21.04	67.41	-14.42	-30.52	-0.08	22.38
Bovine cattle. sheep	1.27	-2.49	-1.67	0.00	-2.90	0.12	-0.21	-0.06	0.00	-0.16
Other meat products	1.43	-1.74	-1.18	0.00	-1.49	0.47	-0.50	-0.21	0.00	-0.24
Vegetable oils. fat	16.22	-14.43	-18.08	-0.03	-16.31	5.44	-4.75	-3.65	0.00	-2.97
Dairy products	1.05	-0.93	-1.14	0.00	-1.02	0.43	-0.26	-0.23	0.00	-0.06
Processed rice	44.59	-39.47	-41.84	-0.08	-36.80	13.60	-20.89	-7.30	-0.01	-14.60
Sugar	0.14	-0.44	-0.23	0.00	-0.52	0.00	-0.01	0.00	0.00	-0.01
Other food products	8.69	-9.12	-11.37	-0.02	-11.81	2.21	-2.32	-1.23	0.00	-1.34
Beverages & tobacco	48.44	-21.61	-42.75	-0.06	-15.97	32.01	-14.55	-18.05	-0.02	-0.61
Textiles	*113.01*	*-4.63*	*-90.21*	*-0.23*	*17.94*	*97.51*	*-45.49*	*-58.12*	*-0.10*	*-6.19*
Wearing apparel	*19.56*	*6.81*	*-11.21*	*-0.06*	*15.10*	*25.25*	*-8.93*	*-13.67*	*-0.03*	*2.62*
Leather products	*4.86*	*-6.07*	*-3.42*	*-0.02*	*-4.64*	*2.05*	*-1.51*	*-0.76*	*0.00*	*-0.22*
Wood	32.36	-4.41	-23.07	-0.07	4.81	31.95	-7.92	-16.61	-0.03	7.38
Paper & publishing	93.75	-24.06	-68.21	-0.17	1.30	85.02	-22.73	-43.97	-0.08	18.25
Chem. Prod	**1359.66**	**-2.82**	**-861.58**	**0.05**	**495.31**	**1690.34**	**-182.25**	**-738.05**	**1.48**	**771.52**
Other mineral prod	**933.40**	**25.53**	**-641.23**	**-2.12**	**315.58**	**1147.12**	**-10.48**	**-605.85**	**-1.22**	**529.56**
Ferrous metals	**722.91**	**21.92**	**-522.30**	**-1.80**	**220.72**	**833.67**	**-60.13**	**-463.96**	**-0.93**	**308.65**
Other metal	**89.40**	**8.37**	**-70.26**	**-0.29**	**27.23**	**100.35**	**-9.55**	**-58.92**	**-0.11**	**31.77**
Metal products	**40.02**	**1.88**	**-27.59**	**-0.12**	**14.19**	**49.03**	**-2.29**	**-25.22**	**-0.06**	**21.46**
Motor vehicles	29.85	-2.14	-23.81	-0.10	3.80	31.87	-1.75	-16.89	-0.04	13.19
Other trans. equis	19.81	2.86	-13.72	-0.06	8.89	30.24	9.19	-16.20	-0.04	23.19
Electronic equip.	*12.95*	*6.50*	*-7.58*	*-0.04*	*11.83*	*32.23*	*24.39*	*-16.78*	*-0.02*	*39.81*
Other mach & equip.	178.11	15.88	-124.89	-0.51	68.59	226.02	0.92	-119.34	-0.26	107.33
Other Industrys	61.05	15.97	-50.25	-0.15	26.62	70.57	-3.87	-50.23	-0.08	16.38
Water	3.37	0.33	-2.20	0.00	1.51	4.89	0.63	-2.24	0.01	3.28
	2030 vs. 2018					2040 vs. 2030				
Mining	23.09	-4.27	-22.88	-0.12	-4.18	7.65	-22.81	-5.16	0.00	-20.32
Bovine cattle. sheep	0.01	-0.03	-0.02	0.00	-0.03	0.00	-0.01	0.00	0.00	-0.01
Other meat products	0.12	0.06	-0.12	0.00	0.07	0.06	0.22	-0.01	0.00	0.27
Vegetable oils. fat	1.23	0.33	-1.77	-0.01	-0.22	0.57	1.86	-0.44	0.00	1.99
Dairy products	0.12	0.04	-0.15	0.00	0.02	0.05	-0.01	-0.02	0.00	0.01
Processed rice	1.37	-5.69	-1.57	-0.01	-5.89	0.18	-1.64	-0.07	0.00	-1.53
Sugar	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Other food products	0.52	0.28	-0.63	0.00	0.16	0.28	1.17	-0.13	0.00	1.32
Beverages & tobacco	10.33	8.34	-13.15	-0.05	5.48	4.75	5.16	-2.98	0.00	6.92
Textiles	*23.26*	*-29.02*	*-29.02*	*-0.13*	*-34.91*	*6.41*	*-19.29*	*-2.77*	*-0.01*	*-15.65*
Wearing apparel	*6.74*	*-8.43*	*-6.68*	*-0.03*	*-8.40*	*2.00*	*-5.29*	*-0.31*	*0.00*	*-3.60*
Leather products	*0.68*	*0.41*	*-0.44*	*0.00*	*0.65*	*0.34*	*0.34*	*0.05*	*0.00*	*0.73*
Wood	11.68	8.33	-13.04	-0.07	6.91	5.11	-0.64	-2.20	0.00	2.27
Paper & publishing	26.66	-6.93	-31.23	-0.15	-11.66	8.27	-30.79	-3.90	-0.01	-26.42
Chem. Prod	**742.66**	**569.11**	**-459.61**	**4.19**	**856.35**	**395.61**	**654.75**	**-44.34**	**0.32**	**1006.34**
Other mineral prod	**526.00**	**824.87**	**-600.08**	**-2.99**	**747.81**	**297.21**	**741.11**	**-164.91**	**-0.22**	**873.18**
Ferrous metals	**310.91**	**146.68**	**-363.96**	**-1.72**	**91.91**	**122.19**	**-151.09**	**-61.88**	**-0.08**	**-90.86**
Other metal	**32.04**	**-16.83**	**-35.54**	**-0.12**	**-20.45**	**9.89**	**-34.08**	**-2.84**	**0.00**	**-27.03**
Metal products	**20.13**	**15.03**	**-19.97**	**-0.09**	**15.09**	**9.57**	**6.74**	**-1.66**	**0.00**	**14.64**
Motor vehicles	14.42	21.62	-14.72	-0.05	21.27	7.71	9.05	-2.42	0.00	14.34
Other trans. equips	14.23	11.03	-14.87	-0.07	10.32	5.42	-16.48	-2.02	0.00	-13.08
Electronic equip.	*9.67*	*-37.61*	*-12.14*	*0.00*	*-40.09*	*1.44*	*-10.15*	*-0.15*	*0.00*	*-8.86*
Other mach & equip	92.90	67.59	-99.77	-0.46	60.26	40.06	-22.89	-15.39	-0.02	1.76
Other Industrys	23.61	9.81	-33.99	-0.13	-0.70	10.20	14.43	-6.83	-0.01	17.79
Water	3.48	10.52	-1.40	0.02	12.62	3.35	19.69	0.93	0.00	23.98

Table 8. Divisia decomposition results (disaggregated 11 Service industries)

	Scale effect	Composition effect	Technique Effect	residuals	TOTAL	Scale effect	Composition effect	Technique Effect	residuals	TOTAL
	2008 vs. 1997					2018 vs. 2008				
Trade	154.47	2.88	-42.09	0.61	115.86	381.32	-99.56	-50.61	0.27	231.43
Land transport	**374.98**	**75.38**	**-115.44**	**1.22**	**336.14**	**1122.91**	**-34.83**	**-195.53**	**0.55**	**893.10**
Sea transport	**160.43**	**144.00**	**-39.20**	**0.02**	**265.25**	**1717.39**	**2149.45**	**-318.41**	**0.02**	**3548.45**
Air transport	**84.91**	**69.01**	**-23.44**	**0.01**	**130.49**	**691.15**	**688.94**	**-147.65**	**0.01**	**1232.45**
Communication	8.31	2.48	-4.60	0.00	6.19	20.47	-1.76	-6.27	0.00	12.44
Financial services	8.98	1.49	-3.69	0.03	6.81	23.23	-3.08	-4.59	0.02	15.58
Insurance	2.40	0.52	-1.11	0.01	1.81	6.44	-0.32	-1.43	0.01	4.69
Business services	29.96	-2.60	-21.83	-0.11	5.41	48.16	-15.29	-15.38	-0.02	17.47
Recreation & services	25.39	0.79	-12.09	-0.03	14.06	57.22	-9.98	-12.68	0.03	34.59
Public services	198.56	-135.51	-65.48	0.31	-2.13	269.54	-166.77	-35.99	0.23	67.01
Dwellings	0.12	0.07	-0.12	0.00	0.07	0.24	0.02	-0.17	0.00	0.10
	Scale effect	**Composition effect**	**Technique Effect**	**residuals**	**TOTAL**	**Scale effect**	**Composition effect**	**Technique Effect**	**residuals**	**TOTAL**
	2030 vs. 2018					2040 vs. 2030				
Trade	608.71	19.53	-0.47	0.63	628.41	331.39	222.00	52.03	0.05	605.47
Land transport	**2038.82**	**294.19**	**-98.39**	**1.34**	**2235.97**	**1136.17**	**894.54**	**45.63**	**0.11**	**2076.45**
Sea transport	**4005.49**	**-1215.12**	**-994.95**	**0.06**	**1795.47**	**939.57**	**-3753.76**	**-392.48**	**0.00**	**-3206.68**
Air transport	**1592.63**	**34.14**	**-573.87**	**0.03**	**1052.93**	**256.27**	**-2079.45**	**-304.66**	**0.00**	**-2127.84**
Communication	30.19	0.00	-4.01	0.00	26.18	16.65	22.81	0.22	0.00	39.68
Financial services	40.58	7.15	-1.20	0.05	46.59	25.73	38.34	4.35	0.01	68.43
Insurance	10.54	0.28	-0.78	0.01	10.05	5.03	-0.18	0.28	0.00	5.13
Business services	64.97	10.10	-12.87	0.04	62.24	34.48	29.20	-0.23	0.01	63.47
Recreation & services	80.04	-11.21	-8.25	0.14	60.73	35.06	-6.44	3.92	0.01	32.56
Public services	290.95	-105.76	-4.86	0.54	180.87	122.25	-25.38	27.31	0.04	124.22
Dwellings	0.28	0.05	-0.18	0.00	0.15	0.13	0.19	-0.10	0.00	0.22

Table 9. Divisia decomposition results (disaggregated 5 energy industries)

	Scale effect	Composition effect	technique effect	residuals	TOTAL
			2008 vs. 1997		
Coal	0.45	-0.35	-0.27	0.00	-0.18
Crude oil	0.09	-0.06	-0.07	0.00	-0.04
Petrol & Coke	**1624.53**	**383.30**	**-820.64**	**-1.30**	**1185.89**
Natural Gas	40.44	-6.49	-28.51	-0.15	5.30
Electricity	**4235.64**	**567.23**	**-4201.86**	**-9.24**	**591.77**
Total	5901.14	943.63	-5051.35	-10.69	1782.73
			2018 vs. 2008		
Coal	0.62	-0.45	-0.12	0.00	0.05
Crude oil	0.10	-0.09	-0.02	0.00	-0.01
Petrol & Coke	**8948.07**	**1665.02**	**-2772.91**	**-9.39**	**7830.79**
Natural Gas	73.46	-51.55	-16.75	-0.04	5.11
Electricity	**10866.83**	**-1128.60**	**-5051.69**	**-5.76**	**4680.77**
Total	19889.08	484.32	-7841.50	-15.18	12516.72
			2030 vs. 2018		
Coal	1.18	-1.04	-0.10	0.00	0.04
Crude oil	0.15	-0.14	0.00	0.00	0.00
Petrol & Coke	**191934.41**	**24691.99**	**-22008.58**	**-38.98**	**194578.84**
Natural Gas	143.99	-127.04	-8.85	-0.01	8.08
Electricity	**36670.74**	**-21331.21**	**-7517.44**	**-19.89**	**7802.19**
Total	228750.46	3232.56	-29534.98	-58.89	202389.15
			2040 vs. 2030		
Coal	0.46	-0.49	-0.04	0.00	-0.07
Crude oil	0.06	-0.06	0.00	0.00	0.00
Petrol & Coke	**418076.70**	**16295.23**	**-96730.90**	**-0.89**	**337640.13**
Natural Gas	67.41	-58.47	-2.05	0.00	6.89
Electricity	**15782.34**	**-18656.00**	**-3663.99**	**-1.18**	**-6538.84**
Total	433926.96	-2419.79	-100396.99	-2.07	331108.11

Figure 1. Economic growth, energy consumption and SO2 emission situation (per capita level)

(Data source: WDI (2003), China Statistic Yearbook and China Energy databook, 6.0)

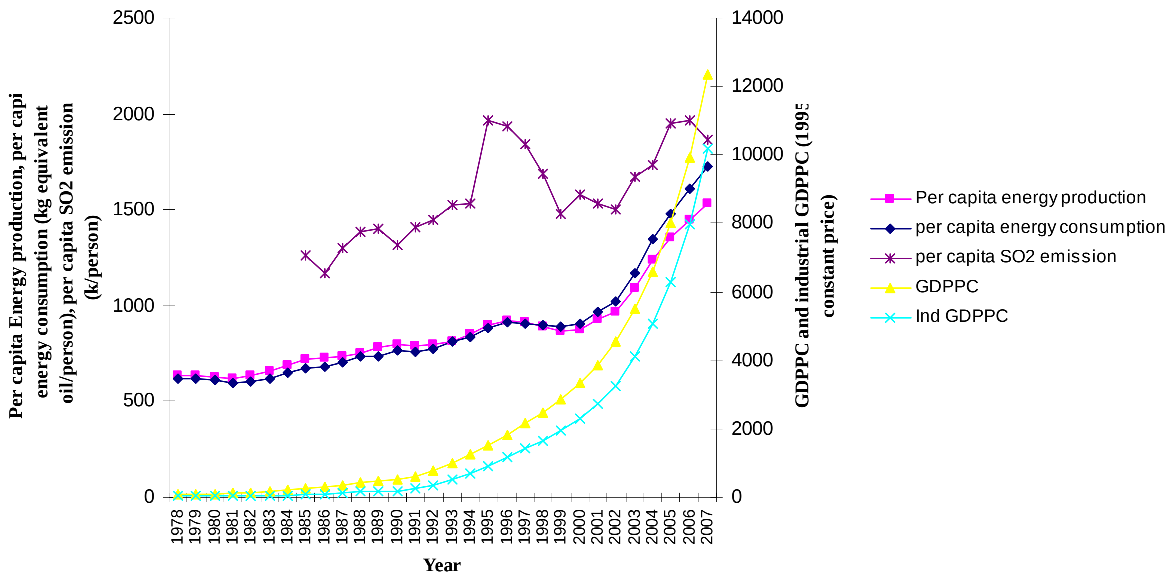
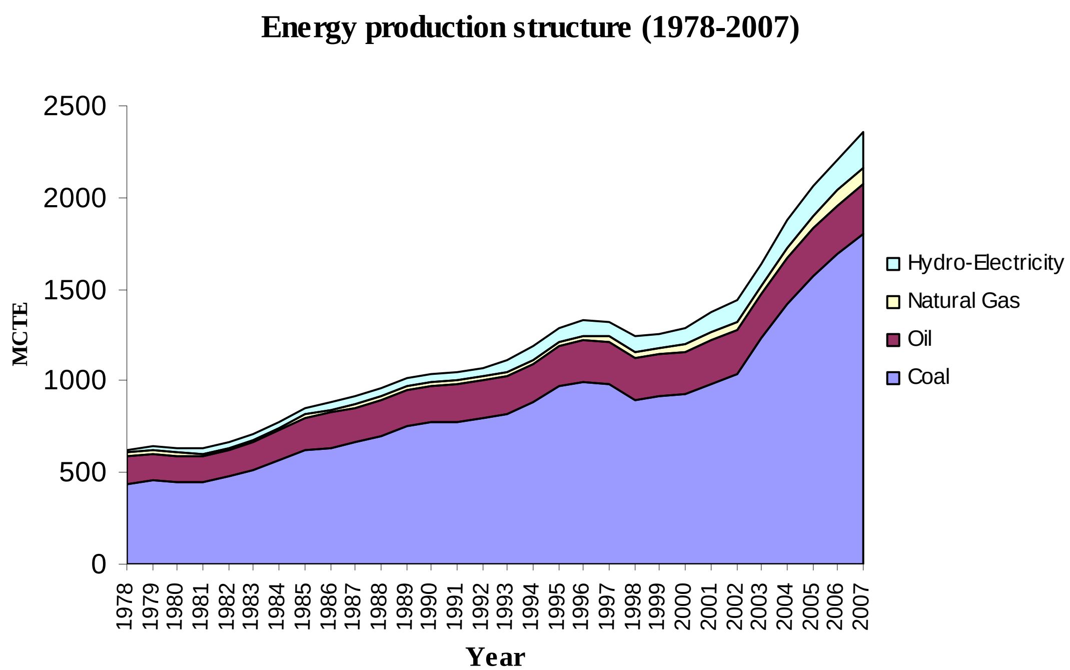


Figure 2. The structure evolution in energy production and consumption in China

Data sources: China Statistic Yearbook (various issues) and China's energy databook, 6.0



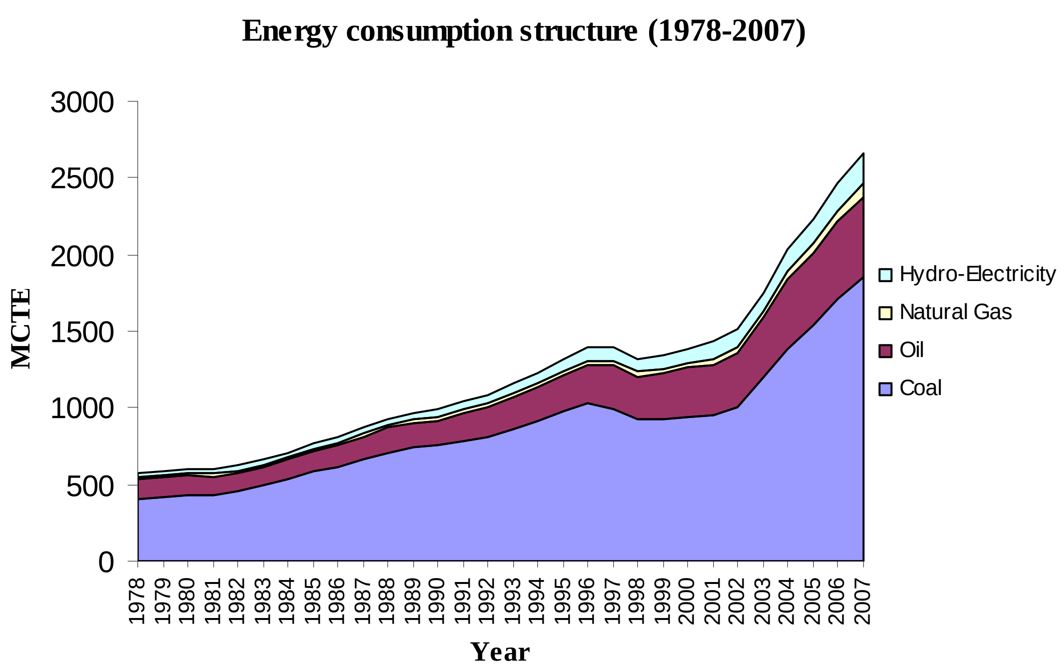


Figure 3. Evolution of China's crude oil demand and supply (1978-2007)

Data sources: China Energy Databook 6.0 and China Statistic Yearbook

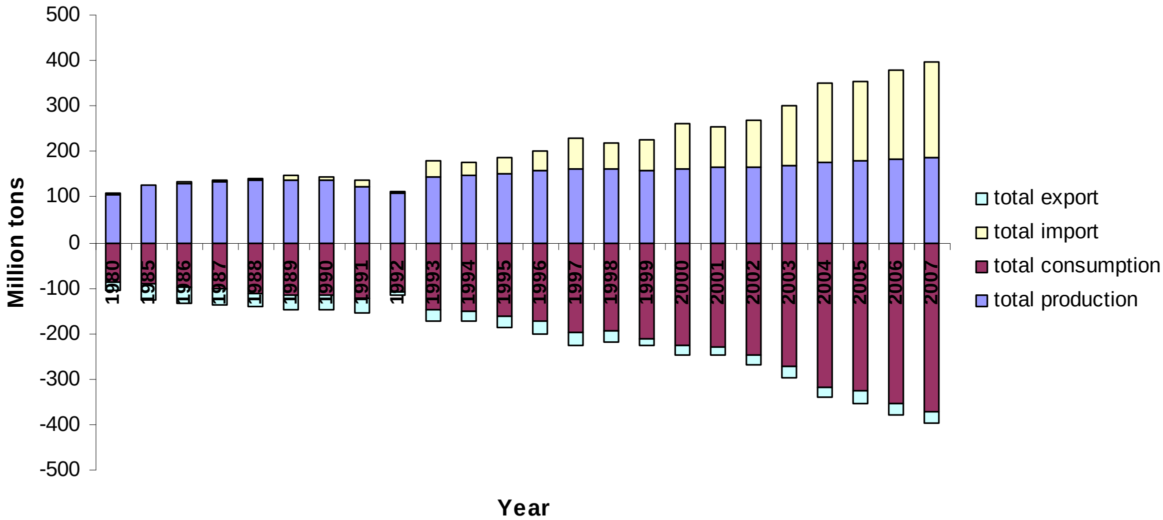
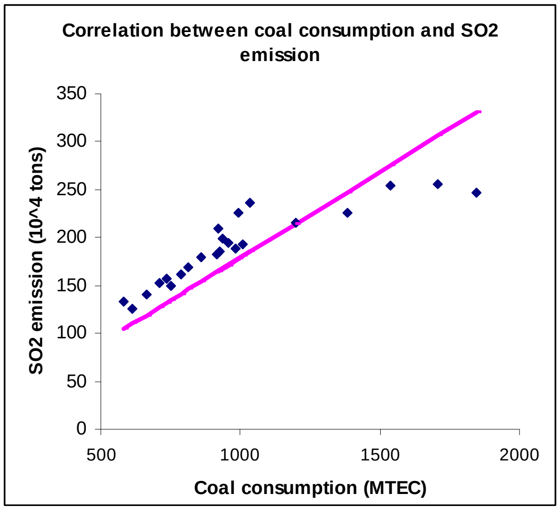
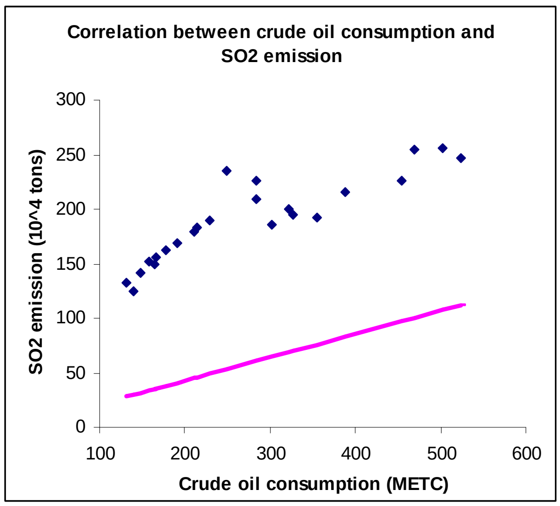


Figure 4. The possible correlation between fossil fuel consumption and SO2 emission

Data source: China Statistic Yearbook, China Energy databook, 6.0

(The blue points give the statistically observed data and the red line describe the estimated correlation)





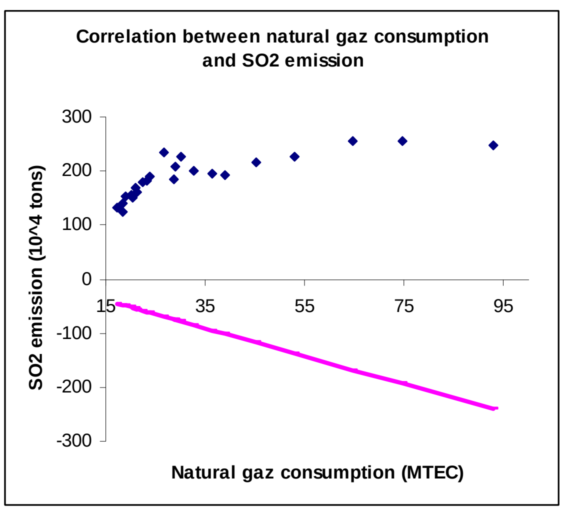


Figure 5. Sectoral Distribution of Total Output (total=100%)

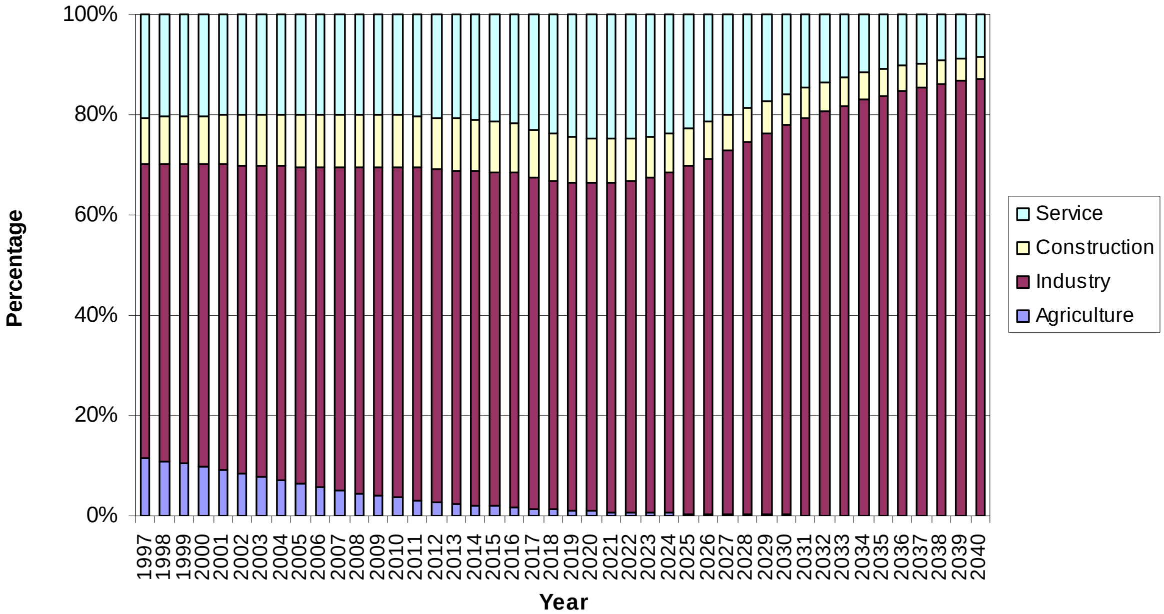


Figure 6. Projected SO2 emission, Real GDP and SO2 emission intensity

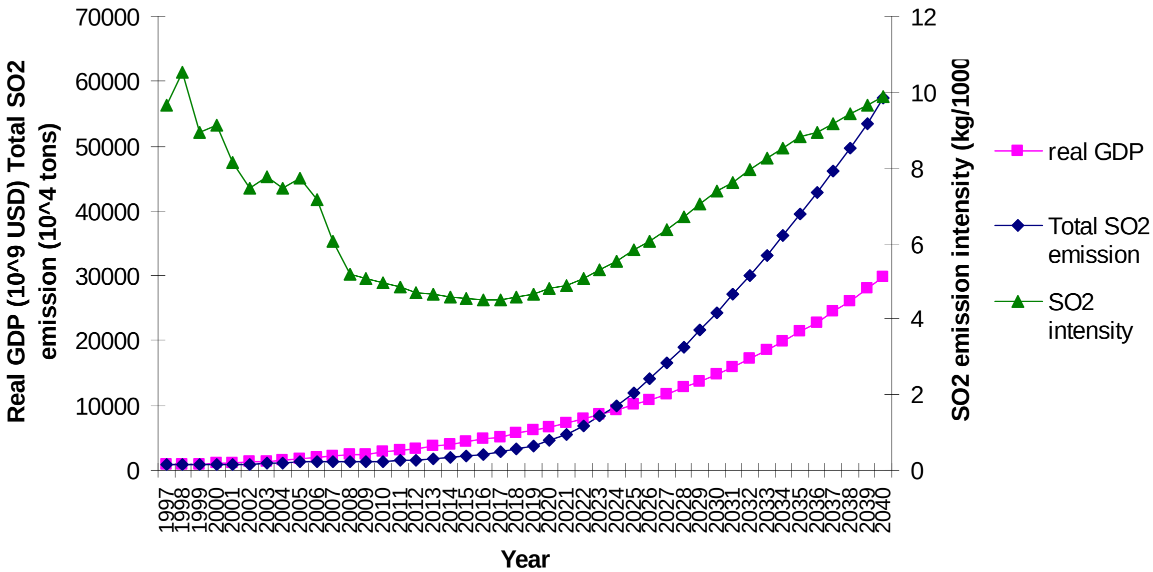


Figure 7. Sectoral Distribution of SO2 emission

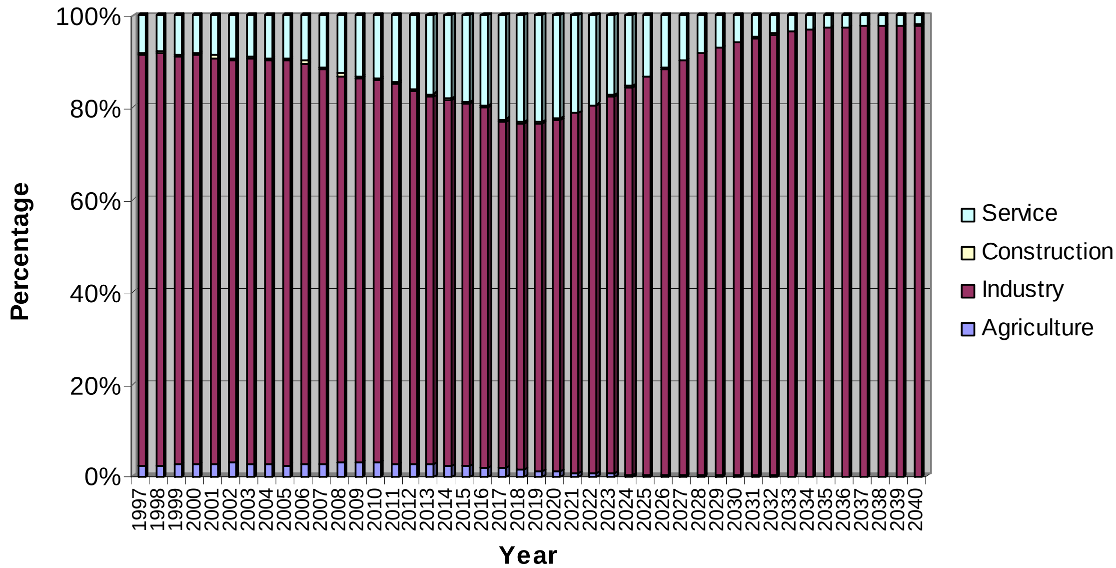


Figure 8. Sectoral emission intensity

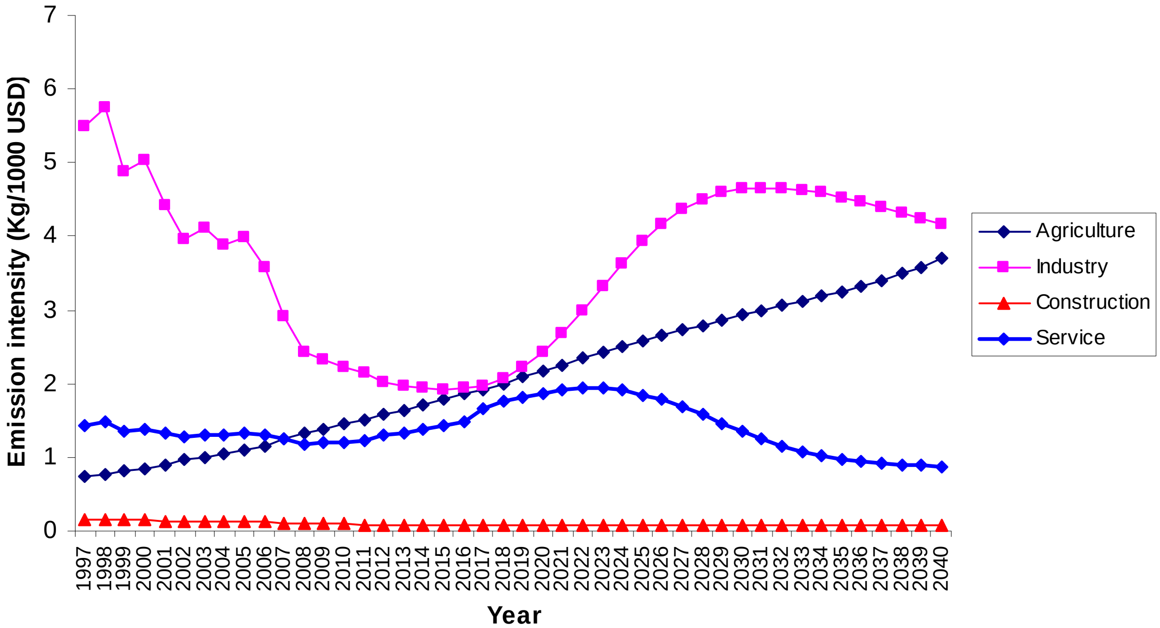
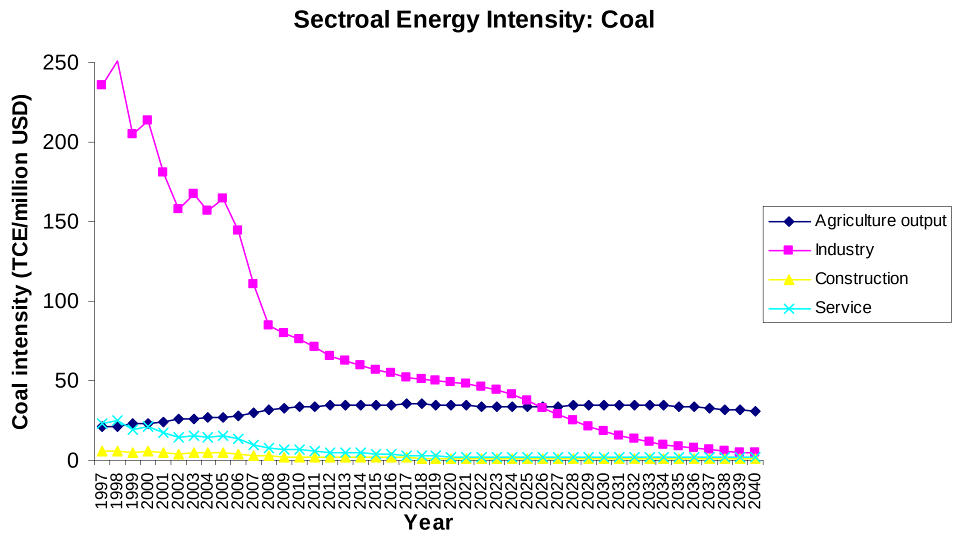
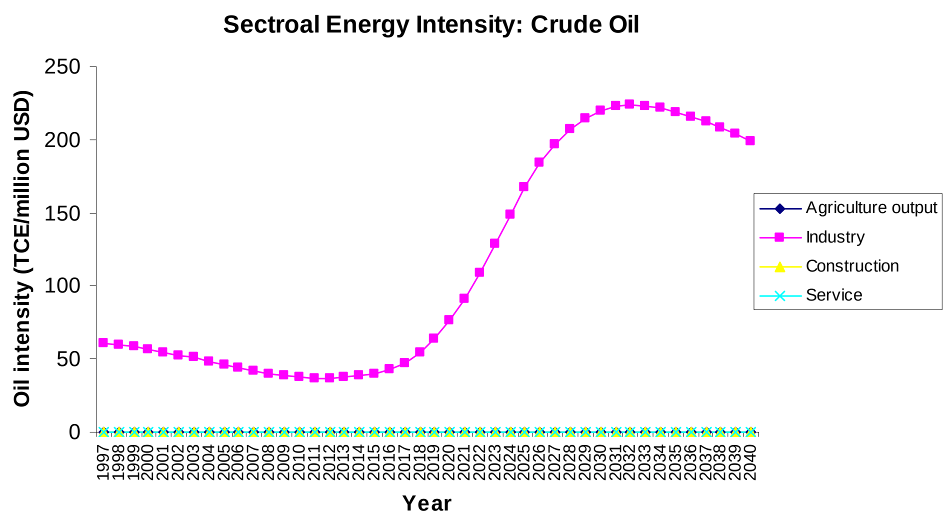


Figure 9. Sectroal Energy Intensity (1997-2040)





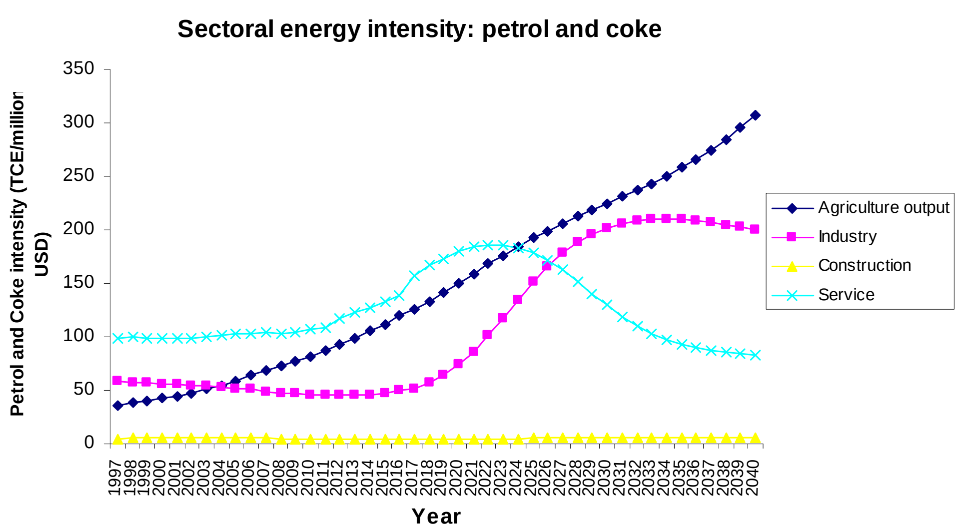


Figure 10. Projected proportion of imported oil in total oil consumption (1997-2040)

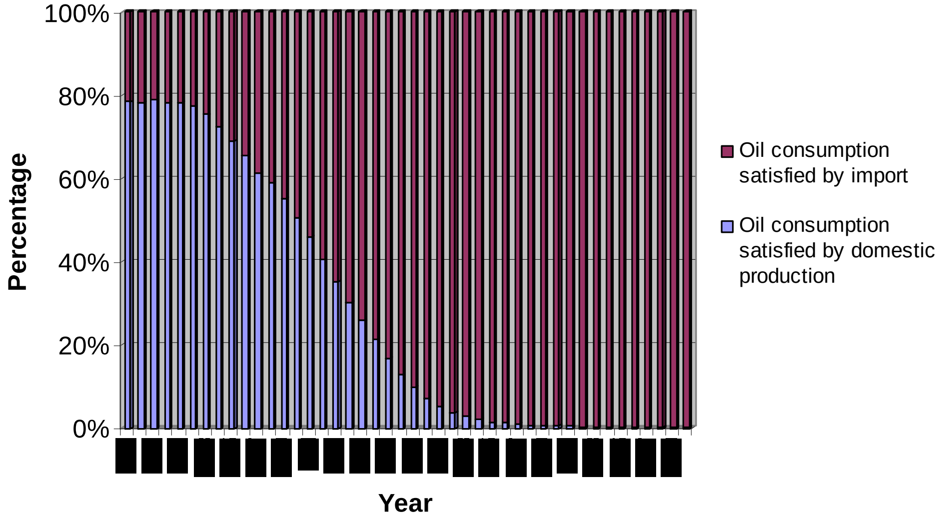
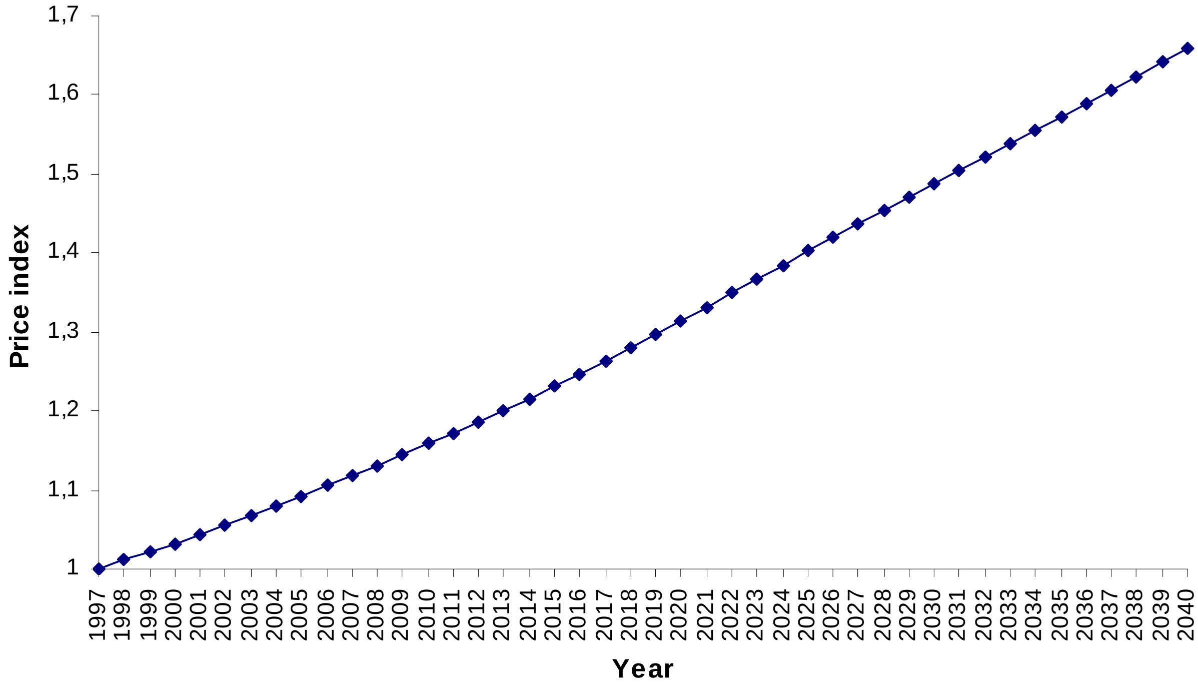
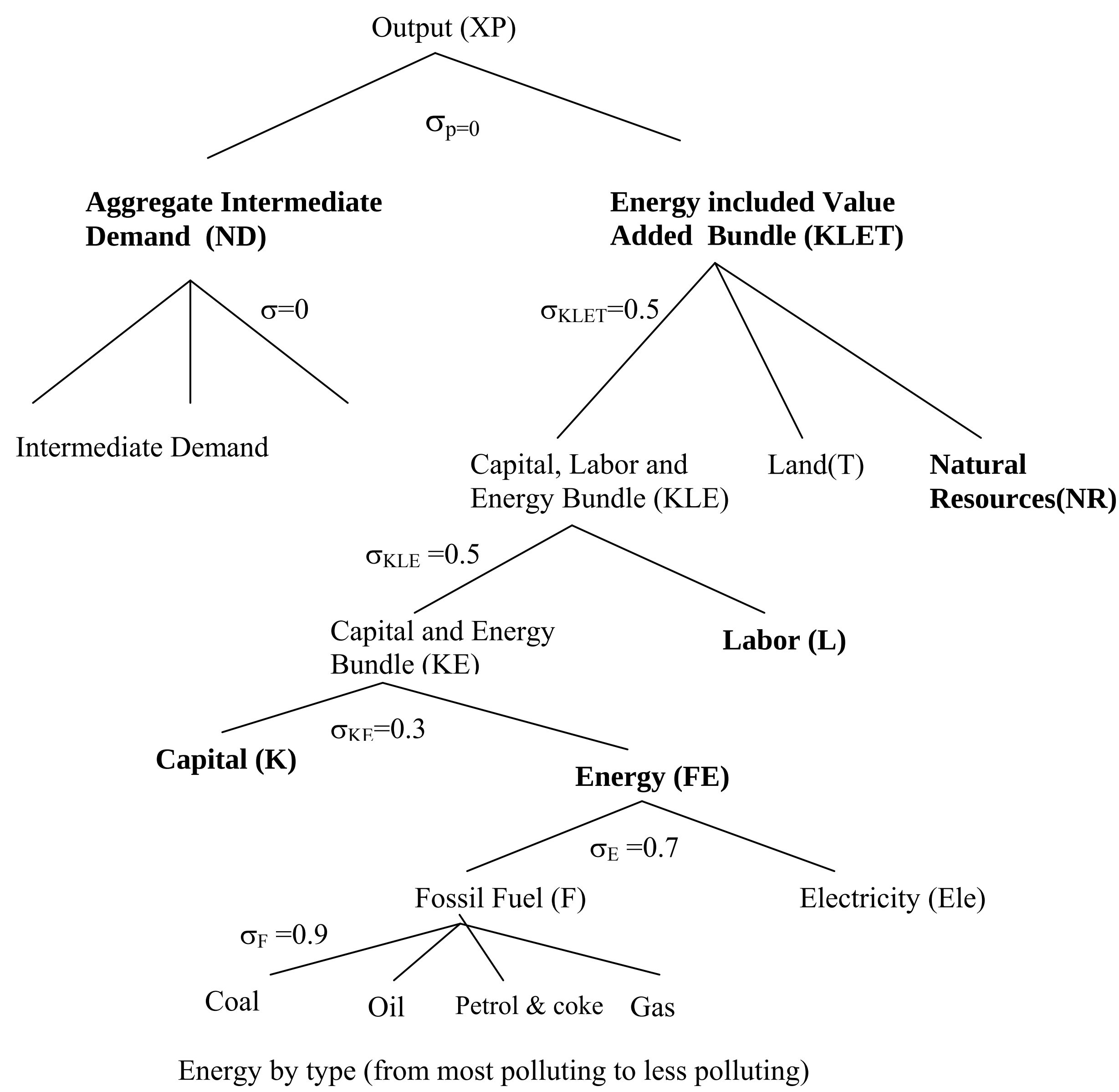


Figure 11. World crude oil price changes under the pressure from China's demand



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.

To capture inelastic domestic production in oil sector, we suppose the price elasticity of the specific natural resource supply for this sector to be 0.01, which is relatively less important than those of the other sectors, generally supposed to be unity. The choice of this elasticity is based on the best fit of our simulation results during 1997-2008 to the data on the proportion of the domestic supply in total domestic demand historically observed in available statistics. In future work, we plan to subject all these parameters to sensitivity analysis.

APPENDIX 3. Anticipated tariff reduction schedule **(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).