THE ECONOMIC COST OF CHINA'S NEW DE-SULFUR POLICY DURING HER GRADUAL ACCESSION TO WTO: THE CASE OF INDUSTRIAL SO2 EMISSION

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April 2004

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EEPSEA is supported by the International Development Research Centre (IDRC); the Swedish International Development Cooperation Agency (Sida); and the Canadian International Development Agency (CIDA).

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ACKNOWLEDGEMENTS

I would like to thank David Roland-Holst of University of California, Berkeley and Mills College for his generous offer to me to share his China prototype CGE model and the related benchmark SAM, also for all his instructive and patient suggestions during the realisation of this research. I would also like to give my thankfulness to the resource person of EEPSEA Ian Coxhead of University of Wisconsin for his helpful and encouraging comments all along research progress. Thanks are also given to David James of Ecoservices Pty Ltd and Nancy Olewiler of Simon Fraser University. Surely I am responsible for all the errors in the research myself.

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EXECUTIVE SUMMARY

To understand the potential impacts of China's accession to WTO in her new de-sulfur policy (gradual reduction of 10% of annual SO_2 emission by 2005 with respect to that of 2000), we construct a CGE model in which SO_2 emission is directly linked to energy input consumption in production. The model equally considers the substitution possibility between energies of different SO_2 effluent ratio by including energy as traditional production factor as labor and capital in the constant elasticity of transformation production function. The positive externality of trade on China's economy is also included. This model is then calibrated into a 55-sector Chinese SAM for the year 1997. Four policy simulations (Business as Usual, Openness policy only, De-sulfur policy only, and the combination of openness and de-sulfur policy) are firstly made for 1997 till 2005. The results show the environmental impact of trade, though proven to be "negative", stays rather modest. This is owing to the industrial composition transformation that deviates the specialisation of Chinese economy towards labour-intensive sector under the new trade liberalization process. We do not find proof for "pollution haven" hypothesis. Although seemingly to be ambitious, the new de-sulfur policy will only bring very slight economic growth loss. The pollution reduction will mainly be realized by the substitution between polluting and less or non-polluting energies. The combination of the trade liberalization and pollution control policies seems to give China more flexibility in adapting her economy to the new de-sulfur objective. Considering different aspect together, the total economy loss due to new de-sulfur policy will be limited to only –0.26% under the presence of trade liberalization. The second part of this research contributes to double dividend analysis, where we further add to the two scenarios in which the new pollution control policy is applied along with two tax reform schemes aiming at reducing the distortion in original producer's tax system. The results confirm the double dividend hypothesis. Instead of transferring directly in a simple lump-sum form to households, the increased environmental tax revenue due to new de-sulfur policy, if used to reduce (either partially or thoroughly) the original distortion in producer's tax, can not only bring obvious economic efficiency and welfare improvement, but also facilitate the substitution of coal by the other less polluting energies and finally aid China to achieve her de-sulfur objective.

Keywords: CGE, Trade, Industrial SO_2 pollution, Energy substitution, Externality, Divisia index decomposition, double dividend, and large country hypothesis.

JEL classification: C68, F18, Q25, Q43.

1.0 INTRODUCTION

China's last ten years' economic growth was characterized by a high growth rate. According to official statistical data, her real average growth rate of GDP steadily stayed over 8 percents during 1990-2000. The per capita GDP almost tripled, from 1634 Yuans of year 1990 to 3843 Yuans of year 2000. While experiencing remarkable expansion of industrial sector (from 37% of total GDP in 1990 to 52% in 1999),[1] like many other East Asian countries, China's economy is in fast integration process into world economy. This is not only reflected in fast increase of her ratio of international trade to GDP, but also marked by the enormous inflow of foreign direct investments.

However, like many of her Southeast Asian neighbors China's economy growth and openness success are accompanied by obvious environmental deterioration. Due to concentration of industrial activities and high population density, since 1980s, SO_2 pollution in China's urban regions has increased dramatically. In over one third of Chinese big cities, SO_2 concentration level is at least twice higher than the standard of $60\mu g/m^3$ fixed by the WHO (World Health Organization) for the developing countries.[2] Some studies have already revealed the negative impact that SO_2 pollution on people's health in China, especially as a significant cause for respiratory diseases.[3] Meanwhile, the ever-expanding acid rain problem both in south and north China aroused by SO_2 emission has resulted in rapid productivity reduction in equipment and soil.[4]

How could we explain China's SO_2 pollution evolution given her economy growth and trade openness trajectory? In spite of the various theoretical assumptions, trade-environment nexus still stays ambiguous. Grossman (1995) regarded pollution as a "joint-product" of production activities determined by the three famous economic characters: scale, composition and technical effect. Concerning the possible trade impact on industrial composition, "pollution haven" hypothesis assumes that given China's low income level, openness process will lead China to be an attractive "world" factory center for pollution industries, since her low income level does not permit her to attach as much importance on environmental quality as their rich trade partners. However, Copeland and Taylor (1994, 1997) and Antweiler, Copeland and Taylor (2001) indicated that besides comparative advantages coming from one country's relative environmental regulation strictness, the traditional comparative advantages determined by natural factor endowment would also be an important factor to influence international production division of the polluting and less- or non-polluting industries. Given China's comparative advantages are in labor-intensive sectors, and that we generally believe labor-intensive industries to be less polluting than capital-intensive ones, China's environmental performance should depend on the weighing of these two comparative advantages that lead China's industrial composition to go in opposite directions. Besides the consideration on composition impact of trade, Porter hypothesis reasons from technical and efficiency aspect, it supposes deepening of openness process might in the long run reinforce production efficiency of China's domestic producer, both through ever-increasing direct import of foreign equipment that embodies advanced technologies and through the positive externality of export frequently used to explain the economy take-off success of the four Asian dragons' economy. Moreover, trade-environment relationship can also be explained from scale aspect. If we regard pollution as a "joint-product" of production, given trade's positive impact on economy growth and enlargement of industrial production scale, if the industrial composition and technical efficiency keep constant, a higher openness degree will result in more pollution. Since trade's

[1] China's Statistic Yearbook, (1990-2000).
[2] China's Environment Statisitic (1998).
[3] Xu et al,1994, Wells, Xu et Johnson, 1994 and World Bank, 1996a.
[4] World Bank, 1996b.

environmental impacts can be traced in all the three aspects, without an appropriate analysis permitting us to include all the three aspects, the theoretical conclusion on the trade-environment nexus will certainly be inconclusive.

Parallel to the ambiguity in theoretical analyses, recent empirical studies on the trade-environment nexus did not achieve coherent conclusion, either. On one hand, most of the empirical analyses did not find evidences to support the negative trade-environment relationship supposed by "pollution haven" hypothesis. Like Tobey (ACT, 1990), Grossman and Krueger (1991), Agras and Chapman (1999) and Antweiler, Copeland and Taylor (2001), their results passed on the information that, whatever is its implication in pollution, "the trade's impact --whether positive of negative-- will be small" since different economic determinants of pollution (scale, composition and technical effect) can be all influenced by trade in different degree and sometimes opposite directions. On the other hand, the empirical studies supporting the "pollution haven" hypothesis are quite limited in number. Most of them, are either based on industrial toxicity data (such as Hettige et al, 1992 and Rock, 1996), a pollution indicator extrapolated from US data and not very widely used in empirical analysis, or directly check the pollution impacts of import and export of certain polluting manufacture goods instead of the general openness measurement (Suri and Chapman, 1998), it is hard to believe their results reveal the general trade-environment stories. Furthermore, since most of the empirical works are carried out by using cross-country data, the credibility to extrapolate the static snapshot of cross-country pollution situation to the dynamic pollution-trade relationship for a single country also seems to be relatively limited. Especially for China, her extremely rich coal resource, as the principal cause for her SO_2 air pollution problem indicates the necessity to include her resource characters in the study of her trade-environment nexus. Since trade can actually furnish two ways to help China to reduce the SO_2 emission related to coal combustion. One is to enlarge import of other domestically limited cleaner energies from the world market and change China's coal-dominated fuel input mix. Another is to import advanced end-of-pipe de-sulfur equipment adapted to coal combustion process.

To understand the role of trade in China's environment becomes more and more important for Chinese economists and ecologists. Entering the new century, China's economy and environment face unprecedented challenges and opportunities. On one hand, according to the related articles in GATT (1994), from the beginning of 2002, China begins to gradually implement her commitments related to the WTO accession, large reduction in tariffs, subventions and gradual phasing out of the NTBs are expected for the following 15 years, with most important changes to happened during the first 10 year. This further deepening open process will unavoidably affect China's economic growth, structure transformation and technological progress and equally her environmental situation. On the other hand, in June, 2001, China's National Environment Protection Agency (NEPA) called for a further cutting down of total annual SO_2 emission by 10% national wide and 20% in the two control zones (Acid-Rain Control Zone and SO_2 Emission Control Zone) by year 2005 basing on the SO_2 emission volume of year 2000.[5] Since the openness policy and the new de-sulfur policy are actually implemented during the same period (2001-2005), it undoubtedly offers us a perfect policy background to analyze the trade-environment nexus for China's case. Given the future SO_2 emission ceiling fixed by the new de-sulfur policy is based on the emission level of year 2000, to attain the new de-sulfur policy's objective, China should reduce, on one hand, the original SO_2 emission growth caused by the "Business as Usual" economy growth, and on the other hand, the further industrial SO_2 emission variations caused by her commitments related to the accession to WTO. If China's SO_2 emission will, as anticipated by "pollution haven" hypothesis, increase with deepening of open process, the new de-sulfur objective will become more costly in future years. On the contrary, if the new de-sulfur policy seems to cost less to

[5] *Beijing Environment, Science and Technology update,* 14, June 2002.

economy growth under the on-going openness process, we can conclude that trade in fact plays an environment friendly role.

To carry on such a country-specific trade-environment study for China require us to take care of, by our best, the complex characters of Chinese economy. During the last eight years, a series of studies focusing on trade-environment relationship for developing countries, based on the 1996 pioneer prototype computable general equilibrium trade-environment model developed by OECD Development Center —the Trade and Environment EQUILibrium Analysis model (TEQUILA), have come up. Such as Beghin et al (1997) on Mexico, van der Mensbrugghe et al. (1998), Beghin et al (1999, 2002) on Chile, and Yang (2001) on case of Taiwan, etc. These studies, though similar in their modeling method managing to capture the trade-environment nexus through both scale and composition aspects, drew quite different conclusion on the role of trade in environment. This actually shows once more the importance of one country's (region's) economic and structural character in determining the role of trade liberalization in environment protection.

In this paper, we apply the recent prototype of a Real China's Computable General Equilibrium Model of Roland-Holst and van der Mensbrugghe (2002). Based on this prototype, we further permit substitutability between different energy inputs and link pollution emission directly to energy intermediary consumption in the production activities as done in the TEQUILA model of OECD to capture the trade-environment nexus existing in both scale and composition aspects. To capture trade's impact on pollution through technical and efficiency aspect, we also include the potential positive trade-externality into the model through both export and import as in De Melo and Robinson (DMR, 1990).

Different from the TEQUILA model, in this paper, instead of directly using the estimated input-based effluents intensities (Dessus et al., 1994) obtained by matching input data from social accounting matrix of United States to the corresponding IPPS pollution data for different economic sector developed by World Bank (Martin et al., 1991), we use the actual SO_2 emission and fuel energy (coal, oil and natural gas) input data in 18 Chinese industrial sectors from year 1991 to 1998 to econometrically estimate (panel data method) the direct energy-specific SO_2 emission coefficients. Given different fuel energies have different emission tax rate, the total emission tax paid by each sector will depend on the quantity and composition of its fuel energy input consumption. Since we suppose substitution possibility between different energy, for a producer, to reduce his emission tax cost, he has two possible ways: to reduce the total energy input consumption or to decrease the proportion of the polluting fuel energies in his energy input bundle.

Considering China's important position as a large exporter in wearing apparel, textile, leather and electronic equipment goods, we also consider the "large country" hypothesis for China in world market of these goods.

This CGE model is then calibrated into a detailed SAM of 55 sectors of China for the year 1997. Using the available statistic data on growth rate of GDP, population and labor forces as the exogenous dynamic factors from 1997 to 2001 and their assumed constant growth rate between 2002-2005, we firstly make the Business as Usual (BaU) scenario in which Chinese economy will continue under current situation. Following, to measure the potential economic cost of the new de-sulfur policy, Desulfur scenario is carried out in which we apply only new de-sulfur policy. In the OPEN scenario, only the foreseen gradual tariff reduction promises during 2002-2005 in China are included. At last, in scenario Desulfur+Open, the new de-sulfur policy is carried out along with the supposed new openness process. To seize the different channels through which trade exerts impacts on environment, we will further employ the Divisia index decomposition method to measure the actual contribution of the different economic determinants in SO_2 emission evolution under these policy application.

Since the scenarios Desulfur and Open+Desulfur assume relatively important increase of government revenue coming from the endogenous emission tax augmentation to meet the emission reduction objective, then, this offers us possibility to test the so called "double dividend" hypothesis (Bovenberg and Mooij, 1994). This hypothesis supposes the recycling of the emission tax revenue to reduce the distortions existing in original tax system instead of a simply "lump-sum" transfer to the consumers will result in not only a better environment but also an economy that is more efficient. In the second part of this research, we made further simulations under the two scenarios where the new desulfur policy is applied to compare two kinds of tax reform schemes aiming at reducing the distortion in original producer's taxation system in China: a universal percentage reduction in producer's tax for each sector and an new universal producer's tax rate for all the sectors.[6]

The organization of the research is as follows. We will firstly provide a short introduction on the evolution of China's de-sulfur policies since year 1978 in Section 2. Section 3 is contributed to model specification. After a concise introduction of the different policy scenarios in section 4, we analyze the trade-environment nexus in Section 5 and 6. Section 7 will be contributed to the "double dividend" hypothesis. Finally, we conclude in the section 8. The detailed model is furnished in the Appendix 4.

2.0 CHINA'S ENVIRONMENT POLLUTION SITUATION AND POLLUTION CONTROL POLICIES

Since 1978, China's SO_2 emission increased quickly with her economic growth, industrial production activities became the largest SO_2 pollution source. From Figure 1,we see industrial SO_2 pollution occupies almost ¾ of the total SO_2 emission during the first half of 1990's. The acid rain problems coming from SO_2 emission, which are initially discovered in the 1980s in some southwest provinces, has been enlarged to many southwest, central, south and northeast provinces due to SO_2 emission increase.[7] Though we observe some amelioration tendency in SO_2 emission situation during 1996-1999, which should be due to the ever-reinforcing pollution control efforts of SEPA in the last years, the absolute level of SO_2 emission still stays at obviously higher level than that at the beginning of 1980s.

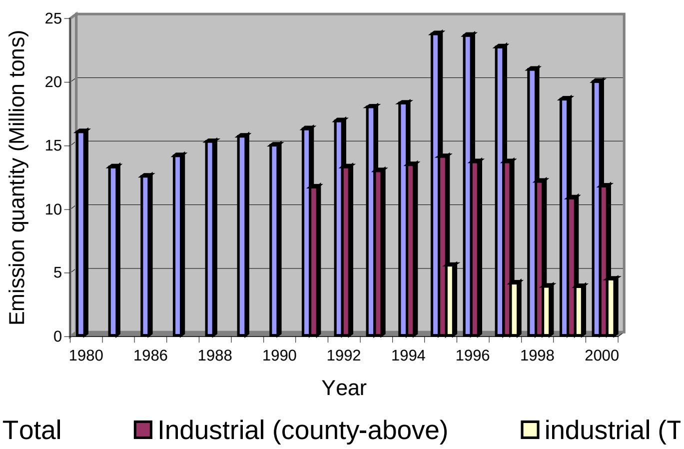

FIGURE 1. Evolution of SO_2 emission in China during economic reform period
Data Sources: China Energy Databook 5.0 and China's Environment Statistics Yearbook

[6] The choices in tax reform scenario designs are limited by the actual information reflected in the 1997 China's SAM, in which only the producer tax revenue is well recorded.
[7] Cao et al (1999).

The current SO_2 pollution control system implemented in China is the so-called "Total Emission Quantity Control (TEQC)" system. Under this system, the polluters, principally industrial and commercial enterprises, are asked to pay for their pollution emission exceeding the relevant national or local pollution standard, and "the original pollution levy rules also stipulated 80% of the levy revenue to be used to fund pollution prevention measures".[8] This system was firstly applied in 1993 in two provinces and nine cities. At the beginning, the implemented emission levy rates were very low (only 1.01 yuans/ton of SO2 emitted at average national level).[9] Although Table 1 shows the policy strictness of this levy system was reinforced during the time and the application areas are also enlarged by covering more provinces (Hebei in 1995 and Shaanxi in 1996), this policy still seemed not to be efficient enough to urge producers to exercise effective emission abatement activities. Given the levy rate "in some cases being only 25% of the pollution control cost",[10] from the econ omic point of view, facing very low levy charge, polluters may prefer to pay levy charge instead of taking more costly measures to abate their emission. Therefore, a large part of pollution reduction in the last ten years observed from figure 1 should be attributed to the pollution abatement initiatives of Chinese environmental regulation authority funded by the over 80% of the revenue collected by pollution levy system. Clearly, further progress in pollution reduction by reinforcing levy system efficiency and strengthening polluters' voluntary abatement initiatives should be expected. This will give government more flexibility to use the emission tax revenue to reduce the other tax distortion, which might help China to realize the so-called "double dividend" in both environment amelioration and economy efficiency improvement aspects.

TABLE 1. Evolution of China's SO_2 pollution levy system in 1990s
(Data source: Cao (1999) and China's Environment Statistic Yearbook, 1991-2001)

	Charge Rate (Yuans/ton)	Scope of Application[1]	Total Charge in 1997 (10^6 Yuans)	Year	SO_2 emission charge revenue (10^6 Yuans)	Average SO_2 Charge in national level[2] (Yuans/ton)
Guangdong Province	200	Coal and oil	58.52	1993	19.7	1.10
Guizhou province	200	Coal	15.97	1994	77.2	4.23
Chongqing city	5 yuan/ton coal	Coal	7.34	1995	122.6	5.17
Yibin City	180	Coal	7.36	1996	146.2	6.20
Nanning City	200	Coal	8.45	1997	179.2	7.36
Liuzhou city	200	Coal	Na	1998	515.095	24.63
Guilin city	200	Coal	Na	1999	861.3262	46.37
Yichang city	200	Coal	11.43	2000	776.031	38.90
Qingdao city	200	Coal	39.41			
Hangzhou city	180	Coal	9.19			
Changsha city	200	Coal	3.89			

Note: [1] Energies in industrial and commercial usage.
[2] We use the total SO_2 charge revenue divided by the total SO_2 emission quantity to get the national level average SO_2 emission levy rate.

From beginning of 1998, SEPA went further in their de-sulfur program and defined the cities and provinces suffering most seriously SO_2 pollution and acid rain problems into two special zones (Acid-Rain Control Zone and SO_2 Pollution Control Zone). In these zones, more stringent pollution control strategies are applied. Since these two zones account for almost two thirds of the national total SO_2 emission, strengthening pollution control in these two zones

[8] Calcaulated by author according to the available emission and emission levy revenue statistics.
[9] Cao et al (1999).
[10] Wang (1996).

actually meant significant progress in total SO_2 control stringency in China, correspondingly, we see a triple of the average SO_2 emission levy rate in 1998 from Table 1.

The plans to reduce total SO_2 emission by another 10% (20%'s reduction for the two zones) in 2001-2005 period is actually the further measure in reinforcing their environmental protection strategy initiated by NEPA. Taking serious this newly established emission control standard (10% less with respect to 2000 real emission level), under the traditional "total emission control" levy system, to reduce the total SO_2 emission by 10% in national level, by how much should we lift the levy rate to activate the initiative private pollution abatement activity that follows profit-seeking rules? How can the levy rate be influenced by the side-by-side trade liberalization policy? How will the influenced levy rate lead the structure and total economy growth to change? How can this source of tax revenue be used to reduce the other distortions in China's tax system? We will try to answer these questions by our analysis.

3.0 MODEL SPECIFICATION

This model is composed of production, income distribution and consumption, other final consumption (investment, government and export service), government revenues and saving, trade, domestic supply and demand, market equilibrium, and macro close rules and dynamics sections. It is then calibrated into the recent China's 1997 SAM.[11] In which the whole economy is divided into 55 sectors: 14 agriculture sector, 29 industrial sectors, one construction sector and 11 service sectors. The energy industries are composed of four sectors: coal mining, oil and coke, natural gas and electricity generation.

The production technology is specified that each economic sector combine capital, labor, natural resource, land, electricity, fossil fuel and other normal intermediate inputs in production. We use a 6-layered nested constant elasticity of substitution (CES)-Leontief production function to design the production of a specific product. The production nesting is shown in Appendix 1.

We suppose that only the energy combustions in production activities emit SO_2 pollution. Inspired by Beghin et al. (1996) and Yang (2001), the production specification distinguishes energy input bundle from other normal intermediate inputs and endow the former continuous substitutability between them. In light of the differing emission properties of, e.g. fossil fuels and electricity, we specify 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.[12] This energy-substitutability arrangement will enable us to be free from the rigid energy input ratio in each unit of product and realize substitution possibility inside the energy bundle and between the energy bundle and other traditional production factors used in production. These model arrangements can help us to seize producer's energy structure adaptation strategy under strengthened pollution control policy and avoid rigid proportional output reductions and is also more consistent with China's SO_2 levy system, which is in fact exercised by imposing a tax on higher effluent rate energies, such as coal and oil used in industrial and commercial activities. Due to data limitation, we are not be able distinguish the pollution abatement activities from production activities in the available SAM data, so we suppose there are no end-of-pipe pollution abatement efforts in production.

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. The most significant relationship exists between coal combustion and SO_2 emissions, and a less important, but still significant

[11] Source: Roland-Holst and van der Mensbrugghe (2002).
[12] Yang (2001) has made a similar arrangement for the energy substitution.

correlation between oil 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.

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 by 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 the whole manufacturing sector in physical unit recorded in the panel database to get the necessary conversion factors. This procedure is shown schematically in equation (1).[13] The conversion factor from physical to monetary units for emission rates for each energy input are given in Table 3.

$$\underbrace{\frac{SO2emission}{energy(moentary)}}_{\text{Emission rate for each monetary unit of energy}}=\underbrace{\frac{SO2emission}{energy(physical)}}_{\text{Emission rate for each physical unit of energy}}\times\underbrace{\frac{energy(physical)}{energy(monetary)}}_{\textbf{Conversion factor}} \quad (1)$$

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).

[13] 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).

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.

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

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

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, savings and total consumption aggregate, 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.[14] 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. The import demand is assumed to follow the small country assumption, perfectly elastic import supply and export demand, so in these cases world prices remain constant. Most of the export demand for Chinese products follows the small country hypothesis, i.e. world prices for export are assumed to be exogenous and export demand from China is perfectly elastic. But we allow the large country hypothesis for certain products in which China possesses very important influence in the world market, such as textile, wearing apparel, leather goods and electronic equipments. For these sectors, profit maximization decisions of producers depend on the trade-off between export volumes and export price that are endogenously determined by foreign markets' demand, which has finite price elasticity.

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 capital to be 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.

Government revenue comes from a variety of fiscal instruments: production tax, intermediate consumption tax, income tax, final consumption tax, valued added tax, import

[14] 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.

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.

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 include 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 obtained, energy-specific SO_2 emission tax rate 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.[15] De Melo and Robinson (1990) on the case of South Korea, and then Rodrigo and Thorbecke (1997) on the case of Indonesia have managed to capture the potential positive externality of trade (through both export and import) into productivity and economy growth in their CGE specification. To seize this possible externality from trade in Chinese economy, we also have gone a little further to specify a positive growth externality arising from trade (through both exports and imports) and increasing domestic productivity.

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

$$Y_j = AT_j\left[a_k(\lambda_k \times K_j)^{\rho} + a_{ene}(\lambda_{ene} \times ENE_j)^{\rho} + a_l(\lambda_l \times L_j)^{\rho}\right]^{1/\rho} \tag{3}$$

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

[15] See De Melo and Robinson (1990) and Rodrigo and Thorbecke (1997).

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 (4) 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.

$$KLE_j = AT_j\left[a_k(\lambda_k \times BT \times K_j)^{\rho} + a_{ene}(\lambda_{ene} \times ENE_j)^{\rho} + a_l(\lambda_l \times L_j)^{\rho}\right]^{1/\rho} \tag{4}$$

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

$$BT = \overline{BT} \times \left(1 + \frac{\sum_{hp} M_{hp,t}}{\sum_{hp}\sum_{T=0}^{t} M_{hp,T}}\right)^{\psi} \tag{5}$$

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, which is the accumulation of 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 $BT \geq 1$, so $BT \times K_j \geq K_j$. Here the externality parameter ψ is supposed to be 0.1, following case of Indonesia studied by Rodrigo and Thorbecke (1997).

4.0 POLICY SCENARIOS

The first recursive dynamic simulation aims to find the necessary endogenous productivity growth path for production factors used in industrial and service sectors such that the forecasted GDP growth trajectory can be realized. In this simulation, we employ the available statistic data on growth rate of GDP and population and labor forces growth during 1997-2001 and the forecasted constant economy growth rate between 2002-2005 (see Table 4 for more details).[16] We also suppose energy inputs to enjoy the same productivity growth rate as capital and labor. All policies instruments are held exogenous and constant, except SO_2 emission tax rate, which is permitted to evolve between 1997 -2000 to capture the already achieved pollution reduction results during these years. The capital depreciation rate is 5%.

Table 4 shows the necessary productivity growth trajectory for 1997-2005 period (See Table 4) given the supposed economic growth rate. We firstly include them as exogenous variables in the dynamic simulation for Business as Usual (BaU) scenario, in which all policy instruments stay constant. In this scenario, we only use the calibrated factor productivity growth rate to re-find the supposed economy growth trajectory in the first simulation. Therefore, the BaU is in fact a simulation done in the opposite direction of the first simulation.

Following, to explore the trade-environment nexus, we make three other recursive dynamic simulations for three policy scenarios. To measure the economic cost of the new de-sulfur policy, we implement the Desulfur scenarios, in which the actual 10% SO_2 emission

[16] We suppose the agriculture sectors do not share the same productivity growth rate and their productivity to be constant and exogenous in all the simulations, so are those for land and sector-specific natural resource.

reduction objective is further added to the BaU scenario. We suppose this policy to be achieved gradually during 2001 to 2005 (about 2% each year) with the aid of an endogenous SO_2 emission levy rate gradually increasing. The Open scenario measures possible economy and SO_2 emission changes caused by China's gradual process to access to WTO. Uruguay Round of Multilateral negotiation requires China to gradually reduce her tariff level by 30-36% in different sectors and gradually eliminate her export taxes except some specific merchandise defined in her agreement with WTO. The tariff reduction schedule from 2001 to 2005 for the 55 sectors is given in Appendix 3. Due to data constraint, we suppose a uniform reduction trajectory for the export tax in all sectors by 50% each year with respect to precedent year through 2002 till 2005, which means a total reduction of export tax by 93.75% along the five years. We further impose a sizeable trade shock on China's economy that assumes some exogenous improvement of terms of trade for China's export owing to her integration, which is expressed as increases in world export price faced by Chinese exporters by 1% each year during 2002 to 2005.[17] The policy scenario Desulfur+Open is to combine the two policies together to investigate the possible role of trade in China's SO_2 emission evolution.

In both of the two scenarios in which we apply the new pollution control policies, the increased government revenue obtained from emission levy collection is transferred to the household in a simple lump-sump way. This neutral treatment of the supplementary government revenue is necessary for us to concentrate on the analysis on the potential trade's impact on China's environment and economy. To check the "double dividend" hypothesis, we further designed two reform schemes on producer's tax. One is to reduce the producer's tax in all the sectors by the same percentage from their original tax rate level according to the actual revenue growth; we call it TAUP later on. The other one is to apply a unique tax rate on all the sectors, and we call it TAUG. If we consider the second scheme to be a thorough elimination of the distortion in China's current producer's tax system, the first one can be considered as partial one, since given the reduction in tax rate by the same, the sectors originally bearing higher tax rate (more distorted sectors) will also benefit more tax reduction. We simulate the two tax reform schemes for both the Desulfur and Desulfur+open scenarios. So we have another four scenarios in this step: Desulfur+TAUP, Desulfur+TAUG, Open+Desulfur+TAUP and Open+Desulfur+TAUG.

TABLE 4. The related exogenous variable evolution in simulations

Exogenous variables	Year	Annual growth rate	Exogenous variables	Year	Annual growth rate
GDP (percent)	1997	8.8	Labor Force	1997	10.89
	1998	7.8	(1/1000)	1998	14.79
	1999	7.1		1999	10.72
	2000	8.0		2000	9.68
	2001	7.3		2001	13.04
	2002-05	7.0		2002-05	10.00
Population (1/1000)	1997	10.06	Productivity growth	1997	1.0000
	1998	9.14	trajectory	1998	1.0306
	1999	8.18	*Reference:*	1999	1.0349
	2000	7.58	*preceding year*	2000	1.0310
	2001	6.95		2001	1.0417
	2002-05	7.00		2002	1.0346
				2003	1.0348
				2004	1.0364
				2005	1.0380

[17] This favorable trade shock is added due to the consideration that with a domestic market more open to the world, China's products will also be more favorable than before in the world market. Some items in the agreement of her WTO accession do reflect this possibility.

Note: For the expected growth rate of the three exogenous variables (Population, Labor and GDP), the recently published *2003 China's Statistic Yearbook* gives their actual growth rate during year 2002. Labor force: 10.12%, Population 6.45% and GDP 8.0%. Our expectation is actually quite close to the actually achieved level.

5.0 TRADE-ENVIRONMENT NEXUS ANALYSIS

5.1 Economic and pollution evolution during 1997 to 2000

Before going into the detailed results of the four policy scenario simulations, we first check the evolution of China's economy and SO_2 pollution during 1997 till 2000 to verify the reality-coherence of our model. As shown in Table 5, gross output, absorption and real disposable income all grew by about 25% between 1997 and 2000, correspond well to their actual growth achievement, 28.46%, 23.02% and 24.25%, respectively.[18] Investment growth went faster (41.09% vs. 32.03% in reality), so did the industrial gross output (29.26% vs. 29.39% in reality) and export (27.43% vs.31% in reality). At the same time, due to the reinforcement of SO_2 pollution control, economy growth have been achieved by less than 1 to 1 pollution increase, the total SO_2 emission during the same period grew much slower (10.53% vs. 8.8% in reality). This De-sulfur tendency is even more remarkable for the industrial sectors. An explication for this de-sulfur result should be explained by the parallel slower energy consumption growth, especially for coal (only 4.63% vs. –10% in reality) and electricity (12.83% vs. 17% in reality).[19]

Detailed information on the changes in economic and energy consumption structure is displayed in Table 6-7. As a typical industrializing country, over 58% of China's production output comes from industrial sectors. Within industrial sector, excepts the traditional light industries as textile, wearing apparel and leather products keeping their significant share in total industrial production, the product share of some newly emerging industries as chemical products, ferrous metals, electronic equipment and other machinery and equipment sectors also experience important growth.

[18] Calculated by author according to the official statistic data from China's Statistic Yearbook (1998-2003).
[19] The relatively large difference in coal consumption growth between CGE model simulated results and the actual official statistic data might be due to the missing of the statistics on the consumption supplied by the small coal mines. See Sinton (2001) for more details.

TABLE 5. Macroeconomic changes

Items	Real value							Comparison (changes to reference)				
								2000	BAU	vs. BAU		
	Unit	1997	2000	BaU	Desulfur	Lib	Desulfur+Lib	(vs. 1997)	(vs. 2000)	Desulfur	Lib	Desulfur+lib
Real GDP	10^9 US$	854.69	1073.61	1524.13	1509.64	1535.55	1520.10	25.61	41.96	-0.95	0.75	-0.26
Aggregate output	10^9 US$	2280.77	2859.59	3949.34	3914.08	3946.91	3909.08	25.38	38.11	-0.89	-0.06	-1.02
Industry	10^9 US$	1337.69	1729.16	2514.21	2478.94	2513.18	2474.91	29.26	45.40	-1.40	-0.04	-1.56
Private consumption	10^9 US$	414.09	517.96	692.02	688.80	702.20	698.65	25.08	33.60	-0.47	1.47	0.96
Investment	10^9 US$	310.00	437.37	650.73	646.69	659.31	655.02	41.09	48.78	-0.62	1.32	0.66
Export	10^9 US$	235.93	300.64	454.86	447.33	524.41	515.70	27.43	51.30	-1.66	15.29	13.38
Industry	10^9 US$	209.51	269.08	402.08	394.68	468.16	459.55	28.43	49.43	-1.84	16.43	14.29
Import	10^9 US$	245.26	312.62	479.37	474.64	571.52	565.62	27.46	53.34	-0.99	19.22	17.99
Industry	10^9 US$	214.69	267.60	389.42	387.71	484.76	482.23	24.64	45.52	-0.44	24.48	23.83
Absorption	10^9 US$	830.61	1061.85	1449.27	1442.01	1468.03	1460.19	27.84	36.49	-0.50	1.29	0.75
Real disposable income	10^9 US$	750.34	935.12	1242.08	1236.63	1259.83	1253.77	24.63	32.83	-0.44	1.43	0.94
Per capita	US$	606.95	736.07	943.69	939.54	957.17	952.57	21.27	28.21	-0.44	1.43	0.94
Total wage bill	10^9 US$	388.59	508.35	707.13	696.51	735.41	723.77	30.82	39.10	-1.50	4.00	2.35
Trade balance	10^9 US$	24.08	28.31	34.39	30.78	34.24	30.03	17.57	21.48	-10.50	-0.44	-12.68
Total SO2 emission	10^6 tons	8.26	9.13	11.00	8.21	11.18	8.21	10.53	20.48	-25.36	1.64	-25.36
Industrial	10^6 tons	7.36	8.04	9.55	6.91	9.71	6.90	9.24	18.78	-27.64	1.68	-27.75
Total coal input	10^9 TCE	0.33	0.35	0.38	0.24	0.39	0.24	4.63	9.99	-36.61	1.31	-37.45
Industry	10^9 TCE	0.32	0.33	0.36	0.23	0.37	0.22	4.21	9.83	-37.28	1.39	-38.07
Total oil input	10^9 TCE	0.22	0.27	0.40	0.37	0.40	0.38	26.64	44.37	-6.07	2.16	-4.67
Industry	10^9 TCE	0.16	0.20	0.29	0.27	0.30	0.28	26.94	44.68	-6.40	2.27	-4.99
Total gas input	10^9 TCE	0.02	0.03	0.03	0.03	0.03	0.03	16.22	24.03	8.75	1.87	11.25
Industry	10^9 TCE	0.02	0.02	0.03	0.03	0.03	0.03	16.67	24.60	8.92	1.91	10.83
Total electricity input	10^{12} kwh	1003.29	1132.00	1377.50	1478.48	1408.79	1517.19	12.83	21.69	7.33	2.27	10.14
Industry	10^{12} kwh	845.53	949.73	1156.20	1252.66	1182.33	1285.88	12.32	21.74	8.34	2.26	11.22
Emission tax (1997)	US$ / Kg	0.00545	0.00545	0.00545	0.00545	0.00545	0.00545	0.00	0.00	0.00	0.00	0.00
Emission tax (2000)	US$ / Kg		0.028816	0.028816	0.028816	0.028816	0.028816		0.00	4.11	0.00	4.11
Emission tax (2001)	US$ / Kg			0.028816	0.30	0.028816	0.30			941.09	0.00	941.09
Emission tax (2002)	US$ / Kg			0.028816	0.63	0.028816	0.66			2086.29	0.00	2190.39
Emission tax (2003)	US$ / Kg			0.028816	1.01	0.028816	1.09			3405.00	0.00	3682.62
Emission tax (2004)	US$ / Kg			0.028816	1.47	0.028816	1.62			5001.33	0.00	5521.88
Emission tax (2005)	US$ / Kg			0.028816	2.04	0.028816	2.25			6979.40	0.00	7708.16
Price wedge on coal					104%		113%					
Price wedge on oil					7.4%		8.0%					

TABLE 6. Structure of production in 1997 and variations in 2000

Sector	Share in Gross output (%)		Export/output (%)		Import/domestic sales (%)	
	1997	2000	1997	2000	1997	2000
Agriculture	**11.53**	**12.06**	**2.34**	**0.93**	**3.18**	**4.86**
Manufacturing	**58.65**	**58.43**	**15.66**	**15.57**	**15.99**	**15.63**
Coal	0.50	0.42	10.95	9.96	0.89	0.95
Oil	2.46	2.48	6.69	10.08	16.39	13.04
Gas	0.07	0.06	17.05	20.14	0.00	0.00
Electricity	1.54	1.21	0.61	1.55	0.02	0.01
Mining	1.41	1.49	2.15	1.85	7.92	8.62
Bovine cattle, sheep	0.10	0.09	3.15	2.42	13.34	15.35
Other meat products	0.55	0.51	9.67	4.46	8.66	13.50
Vegetable oils and fats	0.48	0.44	4.91	4.02	30.63	33.35
Dairy products	0.05	0.04	4.17	4.99	21.79	19.92
Processed rice	1.65	1.54	0.82	0.56	0.83	1.03
Sugar	0.03	0.02	21.75	14.74	39.44	46.41
Other food products	1.57	1.42	12.16	9.43	8.02	9.37
Beverages and tobacco	1.78	1.81	2.62	2.13	4.16	4.69
Textiles	5.00	4.82	17.47	16.30	20.11	19.54
Wearing apparel	2.17	2.04	48.61	45.21	9.31	9.42
Leather products	1.69	1.43	54.94	49.47	14.99	16.97
Wood	0.96	0.98	19.13	17.55	8.70	9.21
Paper prod., publishing	1.75	1.73	4.14	4.11	16.57	16.64
Chem. Prod., rub. plast.	6.78	6.87	10.57	12.56	20.26	18.43
Other mineral products	4.58	4.69	5.01	5.21	3.78	3.69
Ferrous metals	3.16	3.27	5.97	6.33	13.28	12.86
Other metal	1.27	1.34	8.12	8.76	19.39	18.63
Metal products	2.43	2.49	12.47	12.92	6.55	6.40
Motor vehicles	1.50	1.52	3.84	4.46	12.88	11.86
Other trans. equipment	1.15	1.20	12.81	13.10	17.66	17.44
Electronic equipment	3.07	3.05	44.79	42.03	45.32	44.28
Other mach. and equip.	8.27	8.59	16.45	17.19	23.22	22.66
Other manufactures	2.51	2.71	39.08	41.35	7.51	7.12
Water	0.18	0.17	0.23	0.37	0.66	0.49
Construction	**9.22**	**9.78**	**0.26**	**0.22**	**0.72**	**0.79**
Services	**20.60**	**19.73**	**4.20**	**4.79**	**4.38**	**4.32**
Total	**100.00**	**100.00**	**10.34**	**10.17**	**10.71**	**10.62**

Industrial sector also has the most important openness degree. Averagely, over 15% of the industrial products are exported and over 15% of the industrial goods in domestic market come from other countries. China's comparative advantage in trade stays in the traditional or emerging labor-intensive industries such as textile, wearing apparel, leather goods and electronic equipment sectors. On contrary, the significant import ratios in some natural resource-intensive sectors (oil and petroleum, food, ferrous metal) and some technique-intensive sectors (chemical products, motor vehicle and other machinery and equipment sectors) in fact manifest China's actual natural and technique constraint. Coherent to the actual statistics, during 1997-2000, we can also observe an increasing export ratio in natural gas industry. Given the zero SO_2-effluent rate of natural gas as energy, we expect the expansion of this sector to be a potential solution for China's SO_2 emission problem, since natural gas can be an important substitute for coal combustion in production.

TABLE 7. Structure of energy consumption in 1997 and variation in 2000

	Coal intensity (TCE/millon USD)		Oil intensity (TCE/millon USD)		Gas intensity (TCE/millon USD)		Electricity intensity (1000 kwh/millon USD)		Share of SO2 Emission (%)		SO_2 intensity (ton/millon USD)	
	1997	2000-1997	1997	2000-1997	1997	2000-1997	1997	2000-1997	1997	2000-1997	1997	2000-1997
Agriculture	**21.16**	**2.18**	**36.09**	**6.44**	**0.05**	**0.01**	**0.24**	**0.03**	**2.40**	**0.28**	**0.75**	**0.11**
Manufacturing	**235.96**	**-45.65**	**119.07**	**-2.13**	**15.70**	**-1.58**	**0.63**	**-0.08**	**89.10**	**-0.99**	**5.50**	**-0.85**
Coal	2.37	-0.22	0.12	0.00	0.03	0.00	0.00	0.00	0.01	0.00	0.04	0.00
Oil	1.05	-0.16	1664.13	-111.47	0.03	0.00	0.00	0.00	11.56	2.15	17.02	-1.14
Gas	1053.06	-127.77	324.32	-9.38	2392.50	-140.22	0.00	0.00	0.41	0.00	22.44	-2.42
Electricity	5274.95	-1044.90	466.91	-53.10	166.36	-23.43	8.07	-1.36	42.88	-4.94	100.57	-19.52
Mining	63.42	-4.78	9.21	0.20	1.66	-0.02	0.59	-0.02	0.48	0.06	1.25	-0.08
Bovine cattle, sheep	67.83	-26.50	6.95	-2.27	0.39	-0.14	0.46	-0.17	0.04	-0.02	1.30	-0.50
Other meat products	8.82	-1.78	0.96	-0.11	0.05	-0.01	0.06	-0.01	0.03	-0.01	0.17	-0.03
Vegetable oils and fats	113.93	-31.63	8.25	-1.66	1.46	-0.33	0.45	-0.11	0.29	-0.07	2.15	-0.59
Dairy products	68.91	-17.91	7.54	-1.37	0.40	-0.08	0.46	-0.11	0.02	0.00	1.33	-0.34
Processed rice	84.22	-20.03	6.04	-0.95	1.08	-0.20	0.34	-0.07	0.72	-0.17	1.59	-0.37
Sugar	42.63	-23.21	3.25	-1.62	0.55	-0.28	0.17	-0.09	0.01	0.00	0.81	-0.44
Other food products	21.92	-9.05	1.74	-0.61	0.28	-0.10	0.09	-0.03	0.18	-0.07	0.42	-0.17
Beverages and tobacco	66.44	-11.54	3.06	-0.27	1.23	-0.14	0.25	-0.04	0.61	-0.04	1.24	-0.21
Textiles	40.87	-6.75	3.60	-0.28	4.21	-0.44	0.32	-0.04	1.08	-0.05	0.78	-0.13
Wearing apparel	10.61	-1.23	1.77	-0.04	0.95	-0.05	0.08	-0.01	0.13	0.00	0.21	-0.02
Leather products	8.53	-1.34	2.39	-0.16	0.53	-0.05	0.07	-0.01	0.08	-0.02	0.18	-0.03
Wood	60.76	-7.01	5.82	-0.13	1.38	-0.07	0.25	-0.02	0.31	0.01	1.16	-0.13
Paper prod., publishing	106.06	-12.86	8.05	-0.23	0.35	-0.02	0.53	-0.05	0.97	0.01	2.01	-0.24
Chem. Prod., rub. plast.	198.62	-31.69	243.89	-17.35	48.96	-4.87	0.91	-0.11	11.42	0.79	6.10	-0.75
Other mineral products	327.96	-36.03	33.84	-0.55	4.56	-0.21	0.61	-0.05	7.96	0.58	6.30	-0.66
Ferrous metals	372.44	-44.61	44.67	-1.22	17.17	-0.98	1.31	-0.11	6.29	0.50	7.22	-0.82
Other metal	109.36	-15.71	22.55	-1.21	8.87	-0.73	1.53	-0.17	0.78	0.06	2.22	-0.30
Metal products	25.29	-2.80	4.37	-0.07	2.97	-0.14	0.38	-0.03	0.34	0.03	0.50	-0.05
Motor vehicles	34.62	-5.00	7.02	-0.38	1.50	-0.12	0.26	-0.03	0.29	0.01	0.70	-0.09
Other trans. equipment	25.11	-2.77	4.23	-0.07	1.30	-0.06	0.28	-0.02	0.16	0.01	0.50	-0.05
Electronic equipment	4.13	-0.62	1.46	-0.09	2.13	-0.19	0.06	-0.01	0.08	0.00	0.09	-0.01
Other mach. and equip.	32.75	-3.61	5.05	-0.08	3.10	-0.14	0.13	-0.01	1.48	0.14	0.65	-0.07
Other manufactures	36.70	-5.04	4.07	-0.19	3.96	-0.30	0.20	-0.02	0.49	0.05	0.71	-0.09
Water	15.23	-2.74	25.29	-2.36	0.34	-0.04	4.18	-0.59	0.03	0.00	0.53	-0.07
Construction	**5.41**	**-0.30**	**4.95**	**0.22**	**0.68**	**0.01**	**0.08**	**0.00**	**0.38**	**0.06**	**0.15**	**0.00**
Services	**23.19**	**-3.38**	**98.56**	**1.38**	**0.84**	**-0.09**	**0.16**	**-0.02**	**8.12**	**0.65**	**1.43**	**-0.05**
Total	**146.11**	**-24.20**	**94.75**	**0.95**	**9.45**	**-0.69**	**0.44**	**-0.04**	**100.00**	**0.00**	**3.62**	**-0.43**

Table 7 shows the consumption situation of the four principal energies and SO_2 emission in some sectors during 1997-2000. Since China's SO_2 pollution problem comes principally from coal and oil combustion, the sectors having highest SO_2 share are generally the industries that consume most intensively coal in their production activities, such as electricity generation, chemical products, ferrous metals and other mineral products sectors. For the other source of SO_2 emission—oil, its consumption is generally concentrated in oil and petroleum, chemical products, electricity and some service sectors. Due to the ever-strengthening efforts in SO_2 pollution control, SO_2 emission intensity shows general declining tendency in all industrial and service sectors during 1997 and 2000.[20] This SO_2 intensity reduction tendency should be explained by the general energy intensity decline in these sectors, especially that in coal and oil. The most important sulfur reduction was also achieved in the most SO_2-polluting sectors, especially in electricity generation sector, whose SO_2 emission reduction, achieved by very important intensity reduction (-19.42%), mainly contributed to the industrial SO_2 emission reduction during 1997-2000. However, since Chinese economy experience an important growth rate during 1997-2000, the total SO_2 emission and total energy consumption still increased. (Table 5).

5.2 Empirical results in the four trade-environment nexus policy scenarios

5.2.1 BaU scenario

Without new policy implication, BaU scenario shows that China's economy will continue her economy growth rhythm. As shown in Table 5, real GDP will further grow by another 42%, with a 20% increase of SO_2 emission as environmental cost. The coal consumption intensity will be further reduced during her economy growth. This reduction will be compensated by the relatively faster increase in consumption of the other energies, especially oil and natural gas.

Without either policy, BAU scenario shows the most possible industrial structure transformation for China given her current industry policies. We can see that China's most important output increase during the next 5 years will happen in industrial sector (45.40%). However, contrary to our expectation, except for the electronic equipment sector, the most important expansion in production will not happen in her comparative advantaged labor-intensive sectors, but in some heavy industries, as metal, machinery, motor vehicle, other transportation equipment, and chemical products sectors. This in fact reveals China's current industrial policy is to "heavilize" her economy, which might be traced from her current production tax structure.

The export and import structure changes and market price changes also reveal the "heavilization" tendency. This is not only reflected by obvious increase of export and reduction of import in most of the heavy industries, such as Ferrous metals, other metal, motor vehicles and other transport equipments, etc., but also by the general market price reduction for these products.

However, this "heavilization" tendency seems not to be accompanied by pollution intensity increase, at least for the case of SO_2 emission. Our simulation results show that, even without further pollution control policies, given the expected technique progress, the general tendency in China for SO_2 emission intensity is to decrease. This is reflected by the generally important decrease in the SO_2 emission intensity in almost all the industrial and service sectors. This should be owed to, as revealed in Table 5, the energy substitution process. We will go into the details of this point later on.

[20] On the contrary, SO_2 and energy intensity of agriculture sectors shows slight increase since emission levy system was not exerted.

TABLE 8. PRINCIPAL SIMULATION RESULTS FOR BUSINESS AS USUAL (BAU) SCENARIO

	Output changes (%)	SO_2 emission intensity changes (%)	Export change (%)	Import change (%)	Market price change (%)
Agriculture	**8.32**	**20.88**	**-61,77**	**3,95**	**38.66**
Manufacturing	**45.40**	**-26.66**	**49,43**	**-1,84**	**0.49**
Coal	12.21	-14.19	-10,65	8,60	6.37
Oil	71.45	-20.49	177,74	-12,78	-11.73
Gas	38.77	-23.90	63,45	-13,74	-5.13
Electricity	41.95	-40.30	285,84	-57,75	-22.74
Mining	53.18	-20.54	31,27	0,92	3.63
Bovine cattle, sheep	-33.70	-27.35	-82,01	6,40	28.79
Other meat products	-4.48	-22.15	-68,25	4,88	25.50
Vegetable oils and fats	9.76	-37.46	-23,32	-0,07	6.06
Dairy products	1.27	-37.34	-29,41	2,70	7.58
Processed rice	8.93	-30.38	-65,70	5,57	32.97
Sugar	-40.09	-25.70	-77,11	8,12	12.24
Other food products	-2.45	-40.06	-59,18	4,02	22.30
Beverages and tobacco	31.79	-34.62	-17,57	1,87	11.92
Textiles	37.16	-32.32	23,07	0,16	-0.21
Wearing apparel	33.88	-22.64	20,44	1,71	1.36
Leather products	-10.65	-18.14	-28,24	2,45	12.87
Wood	45.28	-26.40	28,67	1,72	3.33
Paper prod., publishing	41.88	-25.98	33,96	0,18	1.25
Chem. Prod., rub. plast.	54.26	-28.58	79,02	-8,46	-3.50
Other mineral products	53.06	-26.40	64,07	-4,16	-1.76
Ferrous metals	58.49	-28.11	71,29	-9,19	-1.80
Other metal	63.09	-32.61	76,92	-6,06	-1.82
Metal products	54.53	-26.01	64,15	-1,94	-1.62
Motor vehicles	56.22	-31.56	84,84	-0,69	-3.85
Other trans. equipment	59.23	-26.95	68,51	0,19	-1.35
Electronic equipment	50.30	-31.17	38,50	0,66	-1.14
Other mach. and equip.	58.95	-26.88	71,15	0,27	-1.74
Other manufactures	66.88	-37.09	78,74	1,09	-2.78
Water	58.96	-33.49	186,74	-8,44	-13.73
Construction	**51.06**	**-12.30**	**34,40**	**1,26**	**2.95**
Services	**40.72**	**-5.80**	**82,98**	**-0,40**	**5.88**
Total	**38.11**	**-17.58**	**51,30**	**-1,66**	**-0.40**

5.2.2 Other policy scenarios

Similar to the studies for Mexico and Argentine in Beghin et al. (1997, 1998), we find the new de-sulfur objective will only induce slight foregone for Chinese real GDP (-0.95% for Desulfur scenario). The main contribution to the pollution reduction comes from the general energy intensity reduction and energy composition transformation from coal-intensive to gas and electricity intensive. But relatively, industrial gross output and export will lose more than the average level of the whole economy since their production relies more on energy input uses.

Contrary to many optimists' expectation, further commercial liberalization seems to bring only modest economy growth (0.75% for real GDP). The most manifesting impact of trade liberalization is to enlarge export and import share in Chinese economy. Without a further policy to control SO_2 pollution, trade liberalization will cause SO_2 emission to further increase by 1.64% for total economy, which are obviously higher than proportion vis-à-vis the real GDP growth (0.78%). The energy-output growth contrast is even more obvious for industrial sector, with a slight reduction in total output of -0.06%, the 1.68% increase in SO_2 emission from industrial production reveals an increase in SO_2 emission intensity of 1.74%.

Clearly, simply applying the trade liberalization process will slightly deteriorate the SO_2 pollution problems in China.

Similar to Beghin et al. (1997, 1998), the combined effects of Open+Desulfur policy for most of the macroeconomic indicators' variation are quite close to the additive of Open and Desulfur scenario (except the export and import indices). However, the additive situation cannot be applied to energy consumption. Table 5 shows that the coal and oil consumption reduction and gas and electricity consumption increase in combined scenario are somewhat higher than the additive sum of the two scenarios of separate policy. This actually shows the fact that the Open+Desulfur policy combination can facilitate the substitution of coal by the other three less sulfur-polluting energies.

To achieve the 10%'s SO_2 reduction objective in 2005, For the simple Desulfur scenario, the necessary endogenous emission levy rate need to increase by about 150% each year and finally to attain US$2.04 per Kilo of SO_2 in year 2005 (1997 US$). The corresponding tax rate need to grow a bit faster when the de-sulfur policy is applied side by side with China's openness promise, it need to attaint the level of US$2.25 per kilo of SO_2 in year 2005.[21] The magnitude of the necessary emission levy rate almost stays at the same level as those found in Bighin et al. (1997, 1998). Comparing the original ad valorem wedges added to the energy price caused by the old emission levy rate for benchmark year 1997 (Table 4) with the new ones under the new desulfur policy, we see that the higher emission levy rate will bring much more important ad valorem wedge to energy price when more restrictive emission control policy is applied. For example, the price wedge on coal caused by emission tax in year 2005, in the case of Desulfur+Open scenario will be about 113% and that for oil is about 8.0%.

5.3 Detailed structure changes in output, pollution, energy input uses and price changes

The detailed market price changes in different sectors due to pollution control and trade liberalization policy shown in Figure 2 are actually an intermediate step to understand the detailed structural output and pollution changes. Given the 104% (113%) ad valorem wedge effect of the emission tax on coal price under the single Desulfur policy (combined Desulfur+Open policy), the actual price of coal faced by producer will increase, which in turn lead coal demand to decrease, so for its market price, that is why the actual coal price increase is only 83% (94%) instead of the expected price wedge caused by emission tax. The substitution of the coal by the other cleaner energies will lead the demand for oil, gas and electricity to increase, which in turn make their market price to increase. General price increase tendency of energy products will then cause the cost of the products intensively using energy as inputs to increase, such as electricity, chemical products, ferrous metal, other metal, metal products and the mineral products, etc.[22] The price increase of this product will reduce their market demand, then production factors can be available for the less energy-intensive sectors as textile, apparel, leather product and electronic equipments at lower price, that is why we can observe the general price decrease tendency in these sectors. We observe equally that this less-polluting-sector-favored price structure change is generally even reinforced under the combined policy scenario, which actually reveals the compatibility between the desulfur and openness policy for China's industrial structure specialization and pollution reduction.

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[21] This is equal to 8.34 Yuans per Kg SO_2 according to PPP exchange rate: 1 US$=4.07691 RMB.

[22] Here the price increases effect in the electricity sector should be traced from both the production cost increase due to coal input price growth and the total demand increase due to energy substitution process.

Figure 2. The price effects of different policies[23]

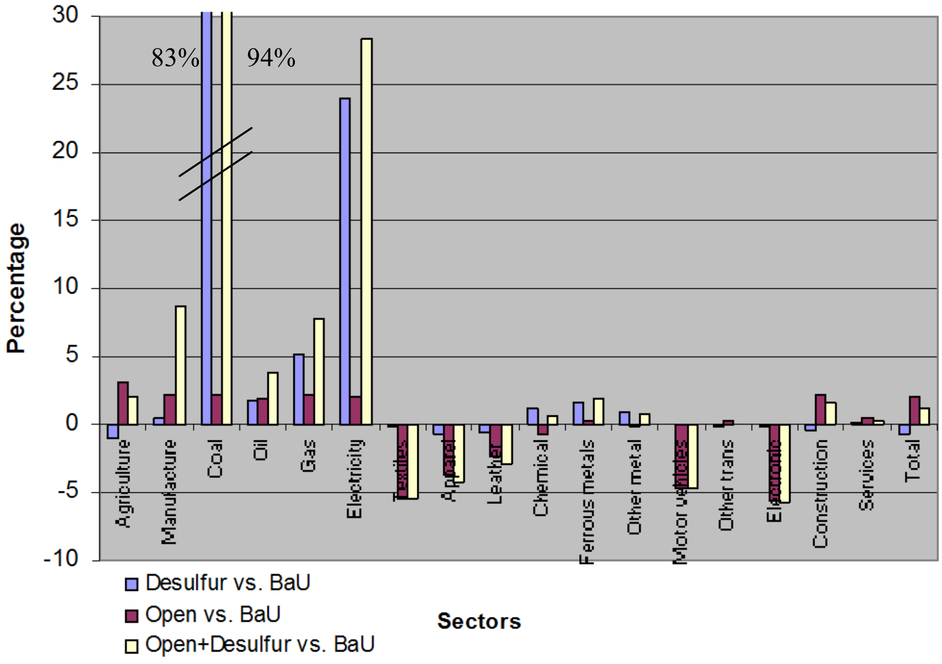


Figure 3 shows the changes of output and SO_2 emission of some sectors under the three policy scenarios with respect to BaU. Since most of SO_2 pollution reduction objective will be achieved in industrial sectors, we concentrate our discussion in industrial sector's changes.

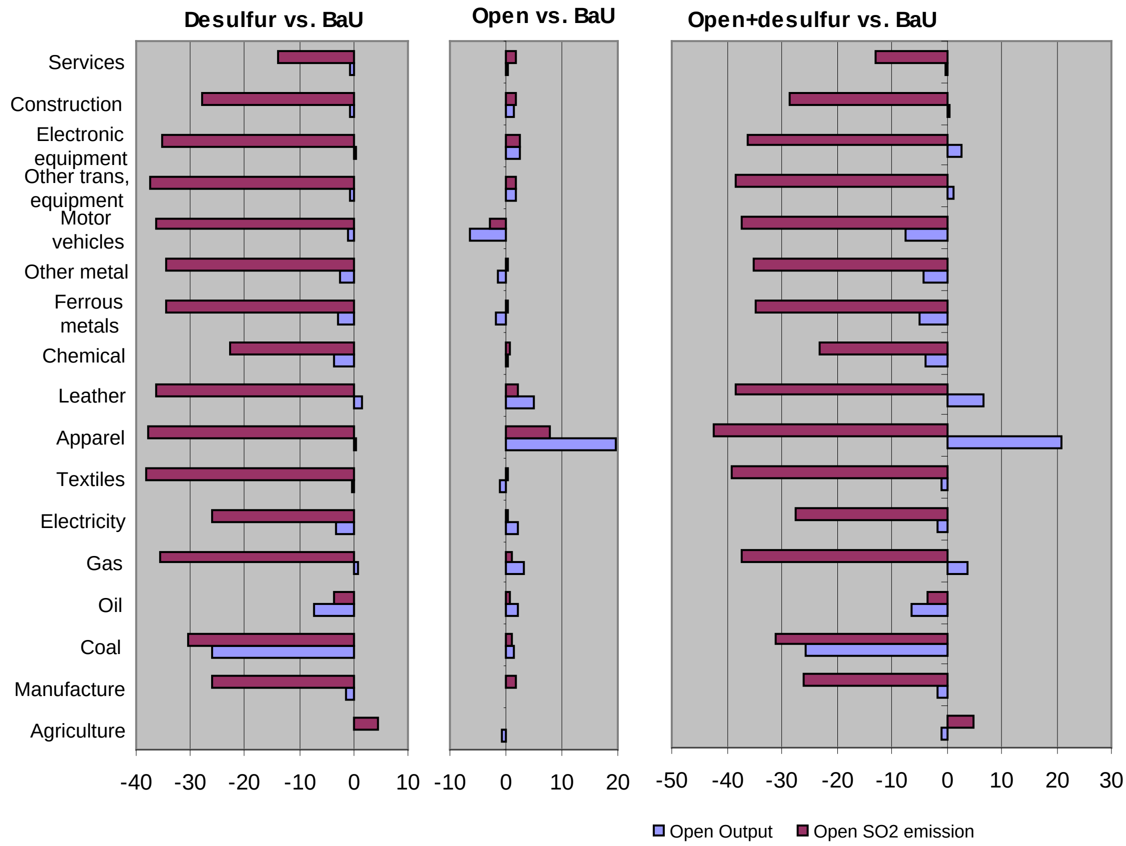
Corresponding to the price structure changes, the new Desulfur policy will actually impede the original "heavilization" tendency since these heavy industries are generally more polluting industries. Besides the three energy sectors, coal, oil and electricity, whose output reduction can also be partially explained by the direct demand reduction in intermediary consumption (-25.99% for coal, -7.41% for oil and –3.24% for electricity), we see that the most important production reduction with respect to BaU scenario happens actually in those heavy industries (chemical products, -3.73%, ferrous metal, -2.88%, other metal, -2.41% and metal product, -1.15%).

Openness policy forecasts significant reduction in many capital-intensive heavy industrial sectors, such as other motor vehicle, -6.42%, other metal, -1.55%, ferrous metals, -1.64%, etc. As supposed by international trade theory, the resources released from these disadvantage sectors will induce a more rapid production expansion in the labor-intensive sectors in which China possesses comparative advantages. Given in addition the favorable trade condition under her WTO accession procedure, we anticipate a further 19.81%'s increase in wearing apparel sectors with respect to BAU scenario and 2.42%'s increase for electronic equipment and 4.99% for leather production. The actual reduction in textile sector's output should be explained by the domination of the price consideration in the profit-maximization decision of the producers facing the downward demand curve of world market under large country hypothesis.[24]

[23] Considering the space limit, we just report the most important industrial sectors in the following several figure. More detailed table with simulation results for all the 55 sectors are available upon request.

[24] The same scenario under the simple small country hypothesis shows the textile sector will also get very important output growth under both Open (5.35%) and Open+Desulfur (5.27%) scenarios.

Figure 3. Output and SO_2 emission changes (%)

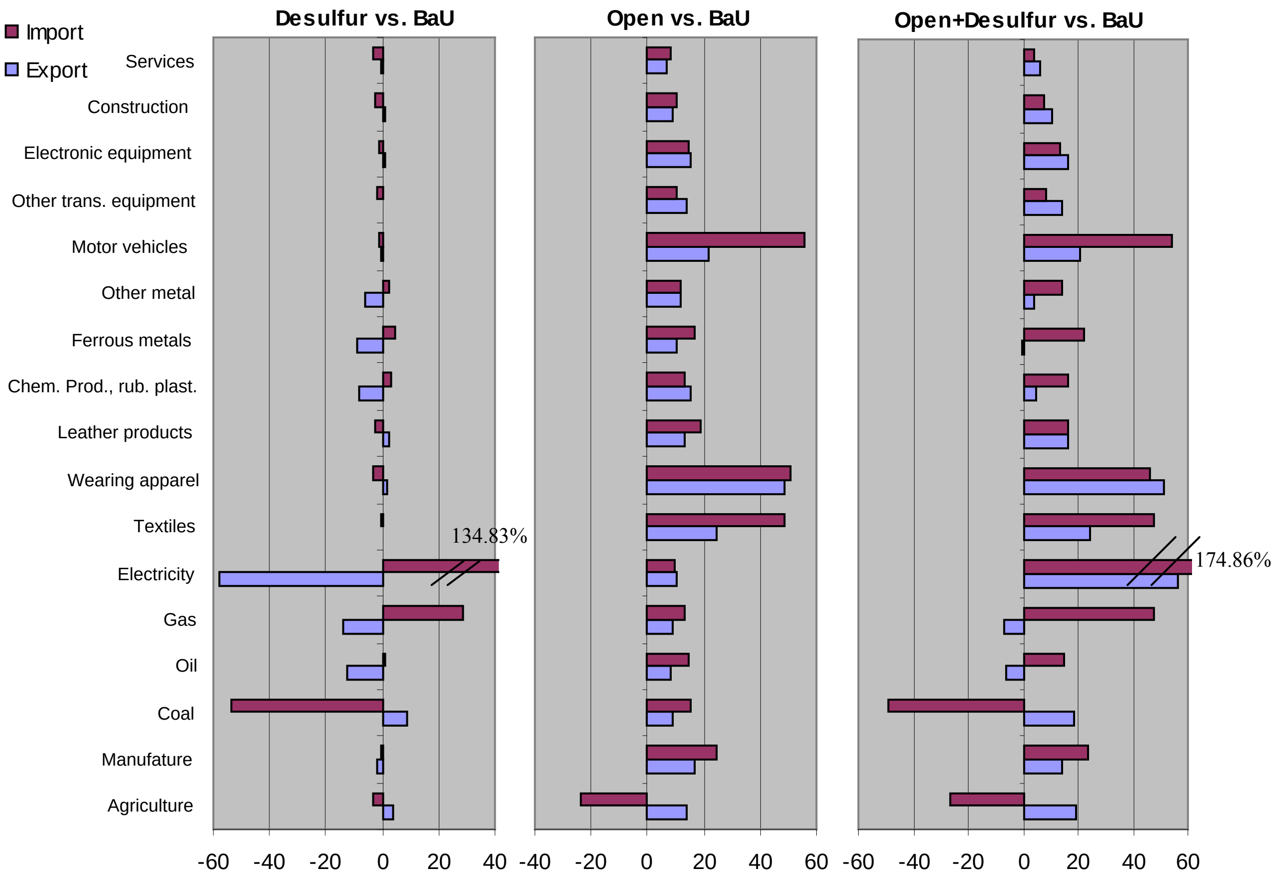


Given that the "labor-intensive" sectors in which China possesses comparative advantages (wearing apparel, textile, leather and electronic equipment) are generally less polluting, and on the contrary, most of the industries giving rise pollution problems (as chemical products, ferrous metal products, other metal products sectors) are actually disadvantage sectors in China. Under Open+Desulfur panel that this labor-intensive deviation tendency in China's industrial composition transformation will be even more obvious. We observe even larger output increase in wearing apparel (20.87%), leather production (6.71%) and electricity equipment (2.83%) sectors with respect to those in Open scenario. Meanwhile, the reduction of product ratio of those polluting heavy industry sectors is also very obvious.

The red bars in Figure 3 show the SO_2 emission changes in different sectors for different policy scenarios. To attain the 10% SO_2 reduction objective, the new Desulfur policy will lead SO_2 emission intensity to further reduce by a quite even way in all the industrial sectors (About -37%). While under the simple presence of trade liberalization, we observe instead the slight increase of pollution intensity of different degree in almost all the sectors. The curious out-of-proportion increase of SO_2 emission for most of the export-oriented sectors, such as wearing apparel (7.8%), electronic equipment (2.51%) and leather products (2.07%) actually reveal that under trade liberalization, the comparative advantage sectors will produce with higher pollution intensity. This might be explained by the fact that improvement of trade terms of these export sectors in fact reduces of the relative cost of pollution tax for producer, since they get generally higher export price for their product. Totally speaking, the 1.68% increase in total SO_2 emission (Table 5) from industrial sectors under Open scenario with respect to that of BaU scenario is in fact the final result of the production structure variations and the uneven sector pollution intensity increase. Combining trade and pollution reduction policy seems to be a good remedial measure for this SO_2 intensity increase situation in most the export sectors. On one hand, Chinese economy can harvest the fruit of liberalization, on the other hand, pollution control policy will impose a more exigent requirement on pollution reduction performance, especially on the export sectors whose pollution performance risks to increase under liberalization. We can see from Figure 3, correspondingly, the significant pollution reduction achievement in most export-intensive sectors (textile, -39.02%, wearing apparel, 42.45%, leather product, -38.44%, electronic equipment, -36.12%), which are even larger than that under simple de-sulfur policy scenario.

As we generally observe the reduction in output ratio for most of the heavy and SO_2-intensive sectors from both the Open and Open+Desulfur scenarios, this reflects the absence of "pollution haven" hypothesis in China. It seems that China's traditional comparative advantage in relatively cleaner labor-intensive sectors actually dominates her environmental comparative advantage as a low-income "pollution haven" for polluting sectors. If we would like to consider trade liberalization as an environment deterioration factor for China's case, it functions rather from relaxing the pollution tax pressure on export sectors than from attracting the polluting sectors' concentration into China's territory.

Figure 4. Trade structure changes under different policy scenarios (%)



The detailed trade variations for different policy scenario are shown in Figure 4. Corresponding to the results of energy composition changes under new pollution policy, net coal export will increase and contrary tendency can be found for the other three cleaner energies. If we agree that the increase of cleaner energy input under simple liberalization policy to be driven by the force from the demand side, the more significant increase of import of the clean energies in the combined policy scenario actually reveals the contribution of liberalization in emission control by opening the clean energy supply from world market and relaxing of the actual restraint on these products in China. That is why although trade liberalization policy will generally facilitate import of all sectors; the most significant import increase will appear in the Open+Desulfur scenario for gas and electricity (47.91% for gas and 174.86% for electricity). Combining trade variations in different sectors, although the dependence of Chinese economy to the imported cleaner energy will increase due to the de-sulfur policy, simulated results show the reduction in China's trade surplus will be quite small: 3.61 billions US$ for the single Desulfur policy scenario with respect to the BaU scenario and 4.21 billion US$ for the policy combination scenario with respect to the single Open scenario, the total trade surplus under the two desulfur policy scenario will stays stable at about 30 billons US$. Obviously, China's export capacity has enough capacity to finance the foreign currency demand coming from her energy structure changes.

5.4 Analysis on the contribution of the different economic aspects on pollution reduction by Divisia parametric decomposition method

Since our CGE model specification distinguish the production and emission from each economic sector, this actually offers us an opportunity to distinguish the contribution of different economic determinants in SO_2 emission variation and their share in final results. Corresponding to the definition of Grossman (1995), on one hand, the enlargement of the total economic scale and transformation of sector composition reveal the contribution of scale and composition effect for SO_2 emission variation. On the other hand, the sector-specified production function as equation (4) also permits us to further distinguish the technical effect in each sector. Furthermore, the inclusion of trade externality and substitutability between energies of different effluent ratio will further allow us to distinguish the technical effect into three aspects: the general technology progress effect indicated as factor productivity λ (we call it as technique effect in our paper), the trade externality effect which is indicated as AT and BT for export and import externality respectively (we call it externality effect), and the possibility to reduce SO_2 emission intensity coming from the substitution of polluting energies by less- or non-polluting energies in production (we call it substitution effect). To better understand how the economic determinants of emission contribute to SO_2 variation under different policy scenarios, we will use the Divisia parametric decomposition method. Therefore, starting from the production function (4), the emission determination function of sector *i* can actually be expressed as equation (6).

$$SO_{2_{it}} = \sum_f \left(\frac{\varphi_f \lambda \times AT \times BT \times X_{f,i}}{Xi} \right) \times \left(\frac{Xi}{\sum_i Xi} \right) \times \sum_i Xi \qquad (6)$$

Where φ_f is the supposed-to-be-constant SO_2 emission rate of energy *f* in our model. X_i means production output in sector *i* and $X_{f,i}$ is consumption of energy *f* in sector *i*. From equation (6), Divisia index decomposition method can decompose the changes in total SO_2 emission under each scenario into variation of its different determinants as equation (7).

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

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

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

$$+\{\sum_f[\,0.5\times(\frac{X_{f,it}\times\varphi_f}{\sum_f(X_{f,it}\times\varphi_f)}+\frac{X_{f,i0}\times\varphi_f}{\sum_f(X_{f,i0}\times\varphi_f)}\,]\times ln(\frac{A_{Ti0}\times B_{Ti0}}{A_{Tit}\times B_{Tit}})\,\} \qquad \text{(Externality)}$$

$$+\sum_f[\,0.5\times(\frac{X_{f,it}\times\varphi_f}{\sum_f(X_{f,it}\times\varphi_f)}+\frac{X_{f,i0}\times\varphi_f}{\sum_f(X_{f,i0}\times\varphi_f)})\times ln(\frac{\frac{X_{f,it}\times\lambda_{it}\times A_{Tit}\times B_{Tit}}{X_{it}}}{\frac{X_{f,i0}\times\lambda_{i0}\times A_{Ti0}\times B_{Ti0}}{X_{i0}}})\,] \qquad \text{(Substitution)} \qquad (7)$$

The decomposition result for the four policy scenarios is recorded in Table 9. Common for all the four scenarios, the most important factor contributing to SO_2 emission increase comes from production scale expansion, in which the single electricity generation sector occupies normally very important percentage. Though composition effect will further exacerbate this pollution deterioration tendency, which can be traced from the generally important positive numbers listed in the composition effect columns, the relatively smaller numbers in the two desulfur-related scenarios show the fact that pollution control policy-led industrial structure transformation does partially limit the SO_2 emission growth potential. Come to the three components of the technical effect. Except for the slight difference in the contribution of trade externality in SO_2 emission reduction caused by trade volume variation under different scenarios, it is the neutral technique and energy substitution effect that make the major contribution to SO_2 emission reduction. Without the new desulfur policy, the most important SO_2 reduction force will be the general technological progress, while for the two scenarios where the desulfur objective is imposed, though both the energy substitution and the neutral technique effect shows very important pollution reduction contribution, the most important role is played by energy substitution procedure.[25]

Comparing BaU and Open scenarios reveals how trade influences SO_2 emission. Besides the slight SO_2 emission increase due to production scale enlargement under trade liberalization, we should notice the desulfur contribution coming from the composition transformation caused by comparative advantage specialization trends under liberalization procedure, although it is actually cancelled out by the rapid expansion of the very polluting electricity and oil sectors facing faster economy growth.[26,27] Trade externality effect, as the most direct technique effect from trade liberalization, has also some supplementary contribution in SO_2 reduction with respect to BaU scenario. However, without additionally specified pollution control policy, trade liberalization itself seems not to be able to contribute to SO_2 emission reduction through the energy substitution channel by enlarging the supply of cleaner energies from world market. Combining these different aspects together, we see the supplementary 180,000 tons' SO_2 pollution increase for China's case under Open scenario, is principally caused by trade-led economic growth and the growth-derived final energy consumption increase, after partially cancelled off by the environment-friendly impact of trade through technical and composition transformation effect.[28]

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[25]The detailed variation of energy input use in different sectors under the four policy scenario is furnished in the Appendix.

[26] Simple calculation can clarify this point. If we put asides energy sectors composition variation, the actual composition effect for Open scenario is 491.34 K tons, which is smaller then that of the BaU scenario, 499.49 K tons. We can see now the actual pollution reduction role of trade liberalization that functions from composition transformation.

[27] The expansion of the energy sectors, especially for the electricity and oil sector, should be explained, on one hand by the increase of input demand for production procedure due to energy substitution, and on the other hand, by the increase of the final demand for luxury goods as the electronic equipment and private vehicles with economy and income growth. According to the simulation results, with income growth during 1997-2005, final demand for electronic equipment and transportation has both doubled.

[28] This result also corresponds well to the conclusion of the cross-country empirical studies of Antweiler et al. (2001), though in China's case the pollution haven hypothesis does not exist.

TABLE 9. DECOMPOSITION OF CHANGE IN SO_2 EMISSION IN BAU SCENARIO (REFERENCE: 1997, DIVISIA METHOD)

Sector	BaU							Desulfur						
	Effect						Δ Emission	Effect						ΔEmission
	Scale	Composition	Externality	Technique	Substitution	Residual		Scale	Composition	Externality	Technique	Substitution	Residual	
Agriculture	**138.28**	**-92.44**	**-3.05**	**0.00**	**74.36**	**0.01**	**117.16**	**139.44**	**-92.32**	**-3.11**	**0.00**	**87.88**	**0.00**	**131.89**
Manufacturing	**4586.78**	**968.12**	**-132.82**	**-2314.04**	**-917.85**	**-0.51**	**2189.68**	**3814.30**	**642.80**	**-107.51**	**-1956.29**	**-2825.46**	**-13.56**	**-445.70**
Coal	0.27	-0.18	-0.01	-0.14	0.03	0.00	-0.02	0.18	-0.22	0.00	-0.09	-0.16	0.00	-0.29
Oil	751.70	451.38	-16.58	-379.24	126.51	0.00	933.78	693.04	335.74	-15.47	-355.45	66.60	0.05	724.52
Gas	21.08	-0.25	-0.47	-10.63	-0.53	-0.01	9.19	16.75	0.34	-0.37	-8.59	-13.73	-0.14	-5.75
Electricity	1938.41	-19.40	-42.76	-977.93	-919.67	-0.25	-21.60	1609.99	-87.85	-35.93	-825.73	-1710.51	-8.10	-1058.13
Mining	28.33	8.03	-0.63	-14.29	3.86	-0.01	25.29	21.60	5.92	-0.48	-11.08	-15.79	-0.15	0.03
Bovine cattle, sheep	0.92	-1.57	-0.02	-0.46	-1.22	0.00	-2.36	0.77	-1.29	-0.02	-0.40	-1.69	0.00	-2.62
Other meat products	0.92	-0.94	-0.02	-0.46	-0.32	0.00	-0.83	0.74	-0.74	-0.02	-0.38	-0.91	0.00	-1.31
Vegetable oils and fats	10.13	-6.19	-0.22	-5.11	-8.29	0.00	-9.68	8.28	-5.11	-0.18	-4.25	-13.19	-0.04	-14.49
Dairy products	0.63	-0.42	-0.01	-0.32	-0.54	0.00	-0.65	0.51	-0.33	-0.01	-0.26	-0.87	0.00	-0.97
Processed rice	27.01	-17.57	-0.60	-13.63	-15.02	0.00	-19.81	21.58	-13.84	-0.48	-11.07	-30.77	-0.09	-34.67
Sugar	0.13	-0.27	0.00	-0.06	-0.25	0.00	-0.46	0.11	-0.23	0.00	-0.06	-0.31	0.00	-0.48
Other food products	5.21	-4.50	-0.11	-2.63	-7.28	0.00	-9.31	4.26	-3.62	-0.10	-2.19	-9.71	-0.02	-11.37
Beverages and tobacco	27.68	-2.57	-0.61	-13.97	-10.27	0.00	0.26	21.74	-1.84	-0.49	-11.15	-26.83	-0.07	-18.63
Textiles	51.28	-0.46	-1.46	-25.87	-14.15	-0.01	9.34	39.85	0.18	-1.15	-20.44	-46.50	-0.20	-28.27
Wearing apparel	6.31	-0.70	-0.18	-3.18	-0.07	0.00	2.17	4.92	-0.42	-0.14	-2.52	-4.32	-0.04	-2.53
Leather products	3.07	-3.41	-0.07	-1.55	-0.53	0.00	-2.49	2.50	-2.71	-0.06	-1.28	-2.47	-0.02	-4.04
Wood	16.43	2.23	-0.50	-8.29	-0.72	0.00	9.15	12.74	1.97	-0.40	-6.54	-11.59	-0.07	-3.88
Paper prod., publishing	50.24	3.25	-1.56	-25.35	-3.03	-0.01	23.55	38.94	2.79	-1.24	-19.97	-36.05	-0.18	-15.70
Chem. Prod, rub. plast.	634.83	211.08	-26.06	-320.27	-42.81	-0.05	456.72	532.42	151.33	-20.29	-273.07	-303.50	0.27	87.16
Other mineral products	445.77	128.19	-17.62	-224.89	-0.96	-0.07	330.42	346.07	98.82	-13.39	-177.49	-285.93	-1.93	-33.86
Ferrous metals	358.97	136.83	-14.75	-181.10	-10.82	-0.06	289.07	277.32	97.05	-10.62	-142.23	-232.59	-1.70	-12.76
Other metal	44.38	20.92	-1.86	-22.39	-5.43	-0.01	35.61	34.45	15.53	-1.40	-17.67	-31.73	-0.27	-1.09
Metal products	19.10	5.87	-0.76	-9.64	0.23	0.00	14.80	14.65	4.50	-0.58	-7.51	-12.52	-0.11	-1.58
Motor vehicles	15.86	5.49	-0.69	-8.00	-2.01	0.00	10.63	12.28	4.32	-0.54	-6.30	-11.94	-0.10	-2.28
Other trans. equipment	9.13	3.56	-0.38	-4.61	0.11	0.00	7.81	7.02	2.82	-0.29	-3.60	-5.97	-0.05	-0.08
Electronic equipment	4.02	0.93	-0.13	-2.03	-0.61	0.00	2.18	3.18	0.82	-0.11	-1.63	-3.03	-0.03	-0.79
Other mach. and equip.	85.29	32.77	-3.54	-43.03	0.98	-0.02	72.45	65.50	26.00	-2.77	-33.59	-55.97	-0.46	-1.30
Other manufactures	28.17	15.45	-1.20	-14.21	-4.75	0.00	23.45	21.63	12.40	-0.94	-11.09	-22.72	-0.13	-0.85
Water	1.48	0.57	-0.03	-0.75	-0.26	0.00	1.02	1.28	0.48	-0.03	-0.66	-0.77	0.00	0.30
Construction	**23.31**	**5.97**	**-0.51**	**-11.76**	**7.73**	**0.00**	**24.73**	**19.14**	**5.08**	**-0.43**	**-9.82**	**-5.26**	**-0.05**	**8.66**
Services	**469.06**	**49.39**	**-10.35**	**-236.64**	**137.78**	**0.06**	**409.30**	**423.20**	**48.72**	**-9.44**	**-217.05**	**6.18**	**1.87**	**253.47**
Total	**5217.43**	**931.04**	**-146.73**	**-2562.45**	**-697.98**	**-0.44**	**2740.87**	**4396.09**	**604.28**	**-120.49**	**-2183.15**	**-2736.66**	**-11.73**	**-51.68**

TABLE 9. (CONTINUE) DECOMPOSITION OF CHANGE IN SO_2 EMISSION IN BAU SCENARIO (REFERENCE: 1997, DIVISIA METHOD)

Sector	Open							Desulfur+Open						
	Effect							Effect						
	Scale	Composition	Externality	Technique	Substitution	Residual	Δ Emission	Scale	Composition	Externality	Technique	Substitution	Residual	ΔEmission
Agriculture	**137.54**	**-95.36**	**-3.28**	**0.00**	**75.89**	**0.01**	**114.80**	**138.79**	**-95.28**	**-3.36**	**0.00**	**90.43**	**0.00**	**130.59**
Manufacturing	**4621.33**	**1070.89**	**-142.99**	**-2334.09**	**-865.79**	**-0.52**	**2348.83**	**3800.50**	**700.25**	**-114.77**	**-1953.83**	**-2874.15**	**-15.27**	**-457.26**
Coal	0.27	-0.18	-0.01	-0.14	0.04	0.00	-0.01	0.18	-0.22	0.00	-0.09	-0.16	0.00	-0.30
Oil	762.27	486.76	-18.19	-385.00	139.73	0.00	985.57	697.77	357.52	-16.87	-358.72	73.12	0.05	752.88
Gas	21.55	1.04	-0.51	-10.88	-0.03	-0.01	11.15	16.84	1.27	-0.41	-8.66	-14.17	-0.16	-5.29
Electricity	1961.65	59.93	-46.82	-990.77	-912.45	-0.26	71.28	1610.49	-30.84	-38.93	-827.95	-1747.46	-9.25	-1043.94
Mining	28.25	7.58	-0.67	-14.27	4.17	-0.01	25.05	21.22	5.45	-0.51	-10.91	-16.28	-0.16	-1.19
Bovine cattle, sheep	0.90	-1.62	-0.02	-0.45	-1.20	0.00	-2.39	0.75	-1.32	-0.02	-0.39	-1.68	0.00	-2.65
Other meat products	0.89	-1.02	-0.02	-0.45	-0.31	0.00	-0.91	0.71	-0.80	-0.02	-0.36	-0.90	0.00	-1.38
Vegetable oils and fats	9.71	-7.30	-0.23	-4.90	-8.17	0.00	-10.90	7.88	-6.00	-0.19	-4.05	-13.08	-0.04	-15.48
Dairy products	0.61	-0.47	-0.01	-0.31	-0.53	0.00	-0.70	0.49	-0.36	-0.01	-0.25	-0.87	0.00	-1.01
Processed rice	26.59	-18.90	-0.63	-13.43	-14.65	0.00	-21.03	21.03	-14.72	-0.51	-10.81	-30.90	-0.10	-36.01
Sugar	0.12	-0.29	0.00	-0.06	-0.23	0.00	-0.47	0.10	-0.25	0.00	-0.05	-0.29	0.00	-0.49
Other food products	4.86	-5.36	-0.12	-2.45	-7.09	0.00	-10.17	3.96	-4.31	-0.10	-2.04	-9.47	-0.02	-11.97
Beverages and tobacco	26.29	-6.23	-0.63	-13.28	-10.77	0.00	-4.63	20.48	-4.67	-0.50	-10.53	-27.08	-0.07	-22.36
Textiles	51.10	-1.36	-1.65	-25.81	-13.42	-0.01	8.85	39.21	-0.41	-1.29	-20.16	-47.16	-0.22	-30.03
Wearing apparel	7.16	1.57	-0.26	-3.62	0.80	0.00	5.65	5.47	1.41	-0.21	-2.81	-4.37	-0.05	-0.55
Leather products	3.17	-3.24	-0.08	-1.60	-0.43	0.00	-2.17	2.54	-2.52	-0.06	-1.31	-2.52	-0.02	-3.90
Wood	16.53	2.30	-0.52	-8.35	-0.33	0.00	9.63	12.65	2.05	-0.42	-6.50	-11.80	-0.08	-4.10
Paper prod., publishing	48.72	-1.64	-1.41	-24.61	-3.28	-0.01	17.78	37.34	-1.03	-1.11	-19.20	-36.65	-0.19	-20.84
Chem. Prod, rub. plast.	638.53	218.86	-27.88	-322.50	-31.92	-0.05	475.04	529.26	150.80	-21.54	-272.09	-306.91	0.41	79.92
Other mineral products	448.10	130.32	-18.54	-226.32	8.72	-0.07	342.21	342.87	98.70	-13.93	-176.27	-291.73	-2.18	-42.53
Ferrous metals	356.27	125.60	-15.47	-179.94	-6.96	-0.06	279.43	271.20	85.28	-11.01	-139.42	-236.90	-1.89	-32.75
Other metal	44.02	19.58	-1.99	-22.23	-5.04	-0.01	34.33	33.70	14.13	-1.47	-17.33	-32.24	-0.30	-3.51
Metal products	19.32	6.27	-0.83	-9.76	0.79	0.00	15.79	14.59	4.75	-0.63	-7.50	-12.75	-0.12	-1.66
Motor vehicles	15.07	3.41	-0.73	-7.61	-2.65	0.00	7.49	11.56	2.66	-0.56	-5.94	-12.33	-0.10	-4.72
Other trans. equipment	9.31	3.94	-0.41	-4.70	0.46	0.00	8.60	7.05	3.09	-0.32	-3.62	-6.05	-0.06	0.08
Electronic equipment	4.12	1.14	-0.15	-2.08	-0.43	0.00	2.59	3.21	0.99	-0.12	-1.65	-3.04	-0.03	-0.64
Other mach. and equip.	85.35	32.23	-3.82	-43.11	2.46	-0.02	73.10	64.67	25.40	-2.96	-33.24	-57.15	-0.52	-3.80
Other manufactures	29.12	17.39	-1.34	-14.71	-2.83	0.00	27.62	22.00	13.75	-1.04	-11.31	-22.56	-0.15	0.69
Water	1.49	0.58	-0.04	-0.75	-0.23	0.00	1.04	1.27	0.48	-0.03	-0.66	-0.77	0.01	0.30
Construction	**23.65**	**6.64**	**-0.56**	**-11.95**	**8.57**	**0.00**	**26.35**	**19.22**	**5.60**	**-0.46**	**-9.88**	**-5.26**	**-0.05**	**9.16**
Services	**473.61**	**56.71**	**-11.30**	**-239.21**	**152.05**	**0.06**	**431.92**	**424.88**	**55.44**	**-10.27**	**-218.43**	**12.10**	**2.12**	**265.85**
Total	**5256.13**	**1038.89**	**-158.14**	**-2585.25**	**-629.29**	**-0.45**	**2921.89**	**4383.39**	**666.01**	**-128.86**	**-2182.14**	**-2776.88**	**-13.19**	**-51.68**

Further comparing the Desulfur and Open+Desulfur columns will give us some synthetic idea about how trade liberalization can help to make the new desulfur objective less costly and how the new desulfur objective can induce trade to show more pollution reduction capability. Although most part of the composition transformation and economic scale reduction is always realized by the direct existence of the desulfur policy and the increased emission levy rate. We see the co-existence of trade liberalization actually helps to reduce the potential cost on economy growth, which is actually shown by the less important scale reduction under Desulfur+Open scenario than that under the single Desulfur scenario. This part of emission reduction will be accomplished, on one hand, by the composition transformation led by China's comparative advantage under the trade liberalization process.[29] And on the other hand, by the higher technical effect, which comes from both the trade externality and energy substitution effect.[30]

6.0 ANALYSIS ON THE DOUBLE DIVIDEND HYPOTHESIS FOR CHINA'S CASE

Till now, in both the scenarios where the new pollution control policy is applied, the government revenue increase coming from environmental tax is simply given to household by a lump-sump transfer from government. In recent years, the studies on the "double dividend" of the environmental reform become increasingly important in the environmental taxation analysis field. According to this hypothesis, the revenues from environmental taxes can be used to cut down other distortion taxes. In this way, the government can reap a "double-dividend"--- not only a cleaner environment, the principal objective of the applied environmental tax, but also a less distorted tax system, which can in turn reduce the economy inefficiency and improve the welfare (Bovenborg and Mooji, 1994, 1997). The two scenarios related to the new Desulfur policy actually offer us a possibility to test this hypothesis, as the emission tax endogenously increased. Therefore, in this section, we will make further modification to the model and suppose government revenue increase coming from the emission tax under the new Desulfur policy will be used to reduce the distortion existing in China tax system.

Most of the existing double dividend analyses are based on the case of European countries. They are generally focused on the possible double dividend effect of environmental tax on the reduction of unemployment by abating the original heavy tax burden on salaries (Bovengberg and van der Ploeg, 1994, 1998a and 1998b, etc.). However, the theoretical literatures on the double dividend hypothesis has not been able to achieve "clear-cut" conclusions, it seems that very restrictive conditions must be met for the recycling of environmental taxation to produce an increase in aggregate employment.[31]

Though the unemployment problem caused by the salary rigidity, heavy labor tax and structure adjustment is almost the most important problem for European economy, considering the absence of labor tax and wage rigidity and the over-supply situation in labor market in China, the employment double dividend analysis might not be not suitable in our research. According to China's labor market character, our original model specification supposes total labor supply is exogenous and the labor market will be cleared up by the endogenously determined efficiency wage rate, which actually denies the necessity for a labor market

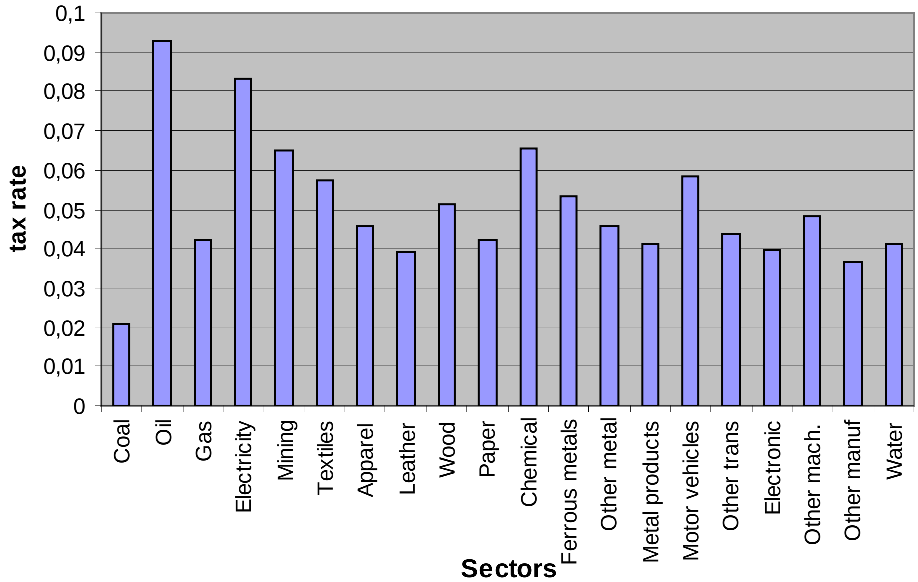
[29] This can be shown by the simple calculation as in note 25. Ignoring the composition changes due to energy sectors' expansion, the difference in the composition effect's contribution in SO_2 emission between the Desulfur and Open+Desulfur scenario will enlarge to 356.27(Desulfur)-338.28(Open+Desulfur)=18. Which means trade liberalization actually increases the contribution of composition transformation in total SO_2 reduction.

[30] Supplementary energy substitution contribution to SO_2 reduction from trade liberalization is 8.37 and the supplementary trade externality contribution is about 40.22. The relatively higher contribution from the supplementary trade liberalization in SO_2 reduction with respect to the actual scale increase is used to cancel off the SO_2 increase caused by energy sectors' expansion.

[31] Carraro et al. (1996).

inefficiency amelioration analysis. However, Figure 5 reveals another important tax distortion in China--the big difference in the producer tax rate in different sectors. Concentrating in the manufacture sectors, we see that China's industrial policy is actually giving obvious priority to food and some heavy industries (as other metal, metal product, other transportation equipments and other manufacture sector). This is reflected by the relatively lower producer's tax applied on these sectors with respects to the other light industrial sectors as textile. Furthermore, as most of the favored sectors in producer tax structure mentioned above generally use energy intensively in their production, the distortion of the producer tax structure is also shown by the unbalanced priority attributed to the coal sectors with respect to the other energy sectors. Given the obvious lower tax rate on coal sector (0.021) with respect to that of t the sectors of oil (0.0928), electricity (0.0834) and gas (0.0420), it is easier for us to understand the current inefficient use and heavy dependence of coal of China's economy. Therefore, in this section, we will see whether recycling the increased emission tax revenue to correct the distortion in producer tax system can help China to get more welfare increase, more economy efficiency, and even better environment performance.

Figure 5. The original producer tax structure in China



Mentioned in the section 4, the two reform schemes on producer's tax that we will test are TAUP, in which the producer's tax on all the sectors will be reduced by the same percentage from their original tax rate level, and TAUG, in which we apply a unique tax rate on all the sectors. We simulate these two tax reform schemes for both Desulfur and Desulfur+open scenarios. Clearly, recycling the increased emission tax revenue to reduce the distortion in producer's tax structure seems to be fruitful. From Table 10, we observe generally more important growth in almost all the macroeconomic indicators with respect the original Desulfur (or Open+Desulfur) scenario. The growth in the economy indicators obtained from the unique producer's tax rate scheme (TAUG) is generally higher than that obtained by the scheme TAUP where we apply a universal percentage reduction in the original tax rate, this result is reasonable since the former scheme can thoroughly eliminate distortions existed in tax system, while the latter can only do partial-elimination. The efficiency gain from tax revenue recycling is less important for Desulfur+open scenario than those for single Desulfur scenario, especially for the TAUP scheme. This might be owing to the fact that trade liberalization process, by reducing export tax and import tariff, also partially contributes to reduction in the original tax system distortion.

TABLE 10. Macroeconomic changes under the double dividend hypothesis

Items	Real value Unit	Desulfur	TAUP	TAUG	Comparisons (% change from Desulfur) TAUP	TAUG	Real value Desulfur+open	TAUP	TAUG	Comparisons (% change from Desulfur+open) TAUP	TAUG
Real GDP	10^9 US$	1509.64	1515.89	1521.24	0.41	0.77	1520.10	1524.40	1531.30	0.28	0.74
Aggregate output	10^9 US$	3914.08	3902.35	3928.45	-0.30	0.37	3909.08	3921.17	3917.67	0.31	0.22
Industry	10^9 US$	2478.94	2511.23	2513.09	1.30	1.38	2474.91	2496.41	2499.85	0.87	1.01
Private consumption	10^9 US$	688.80	689.94	692.29	0.17	0.51	698.65	699.26	702.07	0.09	0.49
Investment	10^9 US$	646.69	646.53	641.92	-0.02	-0.74	655.02	655.12	650.10	0.01	-0.75
Export	10^9 US$	447.33	451.90	452.68	1.02	1.20	515.70	518.42	518.59	0.53	0.56
Industry	10^9 US$	394.68	400.37	399.72	1.44	1.28	459.55	463.15	461.66	0.78	0.46
Import	10^9 US$	474.64	479.50	480.72	1.02	1.28	565.62	568.94	569.89	0.59	0.76
Industry	10^9 US$	387.71	387.30	387.37	-0.11	-0.09	482.23	481.91	481.37	-0.07	-0.18
Absorption	10^9 US$	1442.01	1442.99	1440.73	0.07	-0.09	1460.19	1460.89	1458.70	0.05	-0.10
Real disposable income	10^9 US$	1236.63	1237.94	1241.28	0.11	0.38	1253.77	1254.36	1258.39	0.05	0.37
Per capita	US$	939.54	940.54	943.08	0.11	0.38	952.57	953.01	956.08	0.05	0.37
Total wage bill	10^9 US$	696.51	742.37	744.60	6.58	6.90	723.77	754.57	757.53	4.26	4.66
trade balance(current price)	10^9 US$	30.78	30.46	30.74	-1.07	-0.14	30.03	29.72	30.02	-1.02	-0.04
Total SO2 emission	10^6 tons	8.21	8.21	8.21	0.00	0.00	8.21	8.21	8.21	0.00	0.00
Industrial	10^6 tons	6.91	6.91	6.92	-0.02	0.10	6.90	6.90	6.91	0.00	0.16
Total coal input	10^9 TCE	0.24	0.23	0.23	-3.55	-5.73	0.24	0.23	0.23	-2.41	-5.10
Industry	10^9 TCE	0.23	0.22	0.21	-3.55	-5.66	0.22	0.22	0.21	-2.40	-5.00
Total oil input	10^9 TCE	0.37	0.39	0.40	4.13	6.67	0.38	0.39	0.40	2.73	5.78
Industry	10^9 TCE	0.27	0.29	0.30	5.17	8.58	0.28	0.29	0.30	3.43	7.55
Total gas input	10^9 TCE	0.03	0.04	0.04	6.93	7.56	0.03	0.04	0.04	4.21	5.78
Industry	10^9 TCE	0.03	0.04	0.04	6.32	6.98	0.03	0.04	0.04	4.26	5.20
Total electricity input	10^{12} kwh	1478.48	1576.87	1589.77	6.66	7.54	1517.19	1586.22	1605.58	4.53	5.81
Industry	10^{12} kwh	1252.66	1343.63	1356.86	7.26	8.33	1285.88	1349.44	1368.79	4.94	6.44
Emission tax (1997)	US$ / Kg	0.01	0.01	0.01	0.00	0.00	0.01	0.01	0.01	0.00	0.00
Emission tax (2000)	US$ / Kg	0.03	0.03	0.03	0.00	0.00	0.03	0.03	0.03	0.00	0.00
Emission tax (2001)	US$ / Kg	0.30	0.35	0.39	17.22	30.19	0.30	0.33	0.37	9.10	22.77
Emission tax (2002)	US$ / Kg	0.63	0.75	0.82	19.34	30.25	0.66	0.72	0.80	9.90	21.79
Emission tax (2003)	US$ / Kg	1.01	1.23	1.32	21.56	31.02	1.09	1.22	1.33	12.16	22.87
Emission tax (2004)	US$ / Kg	1.47	1.83	1.96	24.10	32.79	1.62	1.86	2.02	14.50	24.68
Emission tax (2005)	US$ / Kg	2.04	2.59	2.75	26.87	34.88	2.25	2.64	2.86	17.39	27.16

The out-of-proportion growth in total industrial output with respect to that of real GDP and aggregate total output reveals the most important production efficiency improvement from tax reform to be realized in the industrial sectors, whose producer's tax structure is originally the most distorted. The production efficiency improvement effect is also reflected by the out-of-proportion growth of total export, industrial export and total import with respect to that of real GDP, since a more efficiency-based industrial composition transformation under producer's tax reform will unavoidably reinforce China's export capacity and also cause more import demand for the good that she can not produce as efficiently as the other countries. The most important welfare winner from the improvement of production efficiency will be labors, whose total real wage bill shows the most important growth under both TAUP and TAUG schemes. This may also be regarded as another evidence showing that China's actual comparative advantages are in the labor-intensive sectors. This idea can be further confirmed by the result of reduction of the investment generally found in the TAUG reform scheme, since the capital demand should decrease as China's industrial composition becomes more specialized in labor-intensive sectors under both tax reform schemes.

The energy input consumption information listed in Table 10 reveals another benefit from the two tax reform schemes. It is the positive role of the tax reforms in facilitating the substitution of coal by the other less polluting energies. As we saw from Figure 5 that the original producer's tax regime impose a much higher tax rate on oil, electricity and gas sector than that on coal, reducing the tax differences, either partially by TAUP or totally by TAUG scheme will effectively reduce the price gap of these less- (or non-) pollution energies with respect to coal. This will further encourage the profit-maximizing producer to choose these pro-environmental energies in their production, which will further help China to realize her de-sulfur objective.

7.0 CONCLUSION AND POLICY DISCUSSION

The fact that China's WTO accession promise and her de-sulfur policies will be implemented simultaneously during 2001 to 2005 offers us a perfect policy background to analyze the possible trade-pollution nexus in China. In this paper, with aids of a CGE model, we tried to understand the actual role of trade in China's environment situation by combining the implementation of these two policies into the model simulations.

This model offers us the possibility to analyze multiple aspects of the complicated trade-pollution nexus in China, given her actual structural characteristics and her current industrial policy. On one hand, as most CGE models, we assume trade can exert impact on SO_2 pollution by enlarging production scales and encouraging industrial structure to be more specialized according to her comparative advantage characters. On the other hand, we also make a trade-externality specification in the model, which can capture the potential production efficiency gains related directly to trade liberalization. Furthermore, by attributing substitution possibility to energy intermediary consumption, we get one more channel to trace the possible contribution of trade in pollution reduction – facilitating the energy substitution by changing the supply-demand structure of different energies through the trade enlargement. In addition, this model also enable us to measure the efficiency of the currently applied pollution levy system in China and to find the necessary emission levy rate growth path to meet the newly implemented de-sulfur policy.

Our result shows that China's special natural resource endowment situation (rich coal deposit) and her current industry strategy decide her industrialization procedure, even under the presence of the significant technological progress in factor productivity, unless further SO_2

emission control measures, will turn out to be very polluting. According to the BaU scenario simulation, the potential SO_2 emission increase by 33.17%.

However, the environmental impact of trade, though proven to be "negative", stays rather modest. The supplementary increase of SO_2 caused purely by the new openness policy related to China's WTO accession is only 1.64%. The specialization under trade liberalization will encourage the industrial composition to deviate towards less polluting labor-intensive sectors. Moreover, the positive externality of trade that increases production efficiency also contributes to cancel off some of the pollution increase due to the economy-scale-enlarging effect of trade liberalization. We did not find proof for "pollution haven" hypothesis.

Although seemingly to be quite ambitious, the new de-sulfur policy will only bring very slight economic growth loss. Real GDP growth will reduce by only –0.95% vis-à-vis BaU scenario. The most part of pollution reduction will be realized by substituting the polluting energies (coal) by the other less polluting energies (oil, electricity) and non-polluting energy (natural gas).

The combination of the trade liberalization and pollution control policies seems to give China more flexibility in adapting her economy to the new Desulfur objective. The presence of trade liberalization will, firstly, accelerate the industrial composition transformation towards labor-intensive sectors, which are normally less polluting than the capital-intensive sectors; secondly, enlarge the clean energy supply by importing them from other countries and offer producers more chance to further accomplish their energy substitution procedure. And finally, support the contribution of positive trade externality in reinforcing the efficiency of energy combustion in production process. At the same time, the pollution control objective will also encourage producer, especially those in export sectors to further reduce their energy consumption by adding a relatively high emission tax (2.25 US$/Kilo) on their SO_2 pollution results. Considering all these different aspects together, we find the total economy loss due to new de-sulfur policy will be limited to only –0.26% under the presence of trade liberalization, which is remarkably lower than that in the simple Desulfur scenario (-0.95%). Our results in fact prove the good coordination between these two policies for the case of China.

In this paper, we made further simulation to see the potential gains in economy efficiency and welfare from the different usages of the increased environmental tax revenue according to the double dividend hypothesis. We proved obvious economy efficiency and welfare improvement in both the two tax reform schemes designed to reduce the original distortion existing in producer tax system, with larger improvement in the more thorough tax distortion reduction scheme. These economy efficiency and welfare improvement are reflected not only in the growth of aggregate economy indicators, as the obvious increase in total real GDP, total aggregate output, total export and import, but can also be found in the significant structure transformation in pursuing total production efficiency improvement. Encouragingly, as China's original producer tax gives high priority to the raw material (especially in coal sector) and heavy industrial sectors, whose production process are generally more polluting, the new tax reform schemes seem to be able to further contribute to obtaining the new Desulfur objective. On one hand, the tax reform, by reducing the tax priority attributed to the coal sector, can further encourage energy substitution and reduce SO_2 emission. On the other hand, the tax reform, by facilitating the transformation of China's industrial structure according to her real comparative advantages in the labor-intensive sectors, also helps to further reduce total energy input demand and so do pollution.

Although the simulation results seem to describe very optimistic future for China's desulfur perspective, the following points should be borne in mine while interpreting the model result for policy suggestion:

Firstly, China is still quite an imperfect market with frequent government interferences (e.g. recent policies to support domestic auto industry development and banning new power plants in cities located in the sulfur control zone). The perfectly competitive market suggested in this model might not reflect the total reality of China's situation.

Secondly, the modeling in this paper is actually based on some simplifying assumptions. One of them assumes inter-fuel switching to be the main SO_2 reductions contributor. The potential economic cost of the desulfur policy, according to this assumption, actually depends on the inter-energy substitutability. Given China's current situation of limited oil and gas supply and heavy reliance on coal, the potential "technology barrier" for this inter-fuel substitution might be more important than what we expected, especially for heavy industries whose energy intensity is generally high. Since we choose the 0.7 for elasticity of substitution between fuel and non-fuel energy bundles and 0.9 for inter-fuel energy substitution, considering the relatively short time dimension of 5 years, it might be possible that the choice of some lower energy substitution elasticity will make the new desulfur policy significantly more costly. To test the sensitivity of the selected arrangement for the energy bundle, we further run several simulations with lower energy substitution elasticity. The principal economic factors' variations obtained from the simulation based on relatively lower inter-energy substitution elasticity (moderately lower elasticity at 0.5 and 0.7 and very low elasticity at 0.3 and 0.5 for inter-fuel substitution and fuel-electricity substitution, respectively) are listed in Table 10.

Though as expected, the economic cost of the desulfur policy will be somewhat higher when we allow lower substitutability between different energies, we do not observe very important increase in the economic cost of the new desulfur policy, even at very low (0.3-0.5) substitution elasticity. The supplementary economic cost coming from the lower substitution elasticity is about 1.12% in the case of real GDP; in this case, the total final cost due to desulfur will only to rise up to about –1.39%. Higher stability can also be found in per capita disposable income, which shows almost the same numbers under the three different energy bundle elasticity arrangements. The good stability of the model with respect to energy substitution elasticity changes actually can be explained by the Divisia decomposition result indicating the contribution of different economic determinants of emission. Although the lower substitutability will reduce emission abatement from energy substitution process, the industrial composition transformation seems to take more flexible adaptation, given the higher price hike due to the desulfur policy objective and more rigid energy input mix for heavy industries. The less polluting labor-intensive industries will show more increase of their output share in total economy.

Thirdly, from the sensitivity test table, we see that, to obtain the emission reduction goal, only the necessary evolution path of the pollution levy rate shows some obvious sensitivity. The applicability of these high emission levy tax in reality might be difficult to predict. An interesting extension of this model is to combine with some empirical research results on the potential cost of SO_2 pollution to Chinese economy and establish a Pigovian tax that targets the pollution activity according to its actual cost to economy. Given the fact that marginal impact on health ensuing from pollution is decreasing after pollution attains certain level, we expect that the Pigovian tax increase due to the decrease of the inter-fuel substitution elasticity might not be as important as that in the energy-based emission tax used in our model.

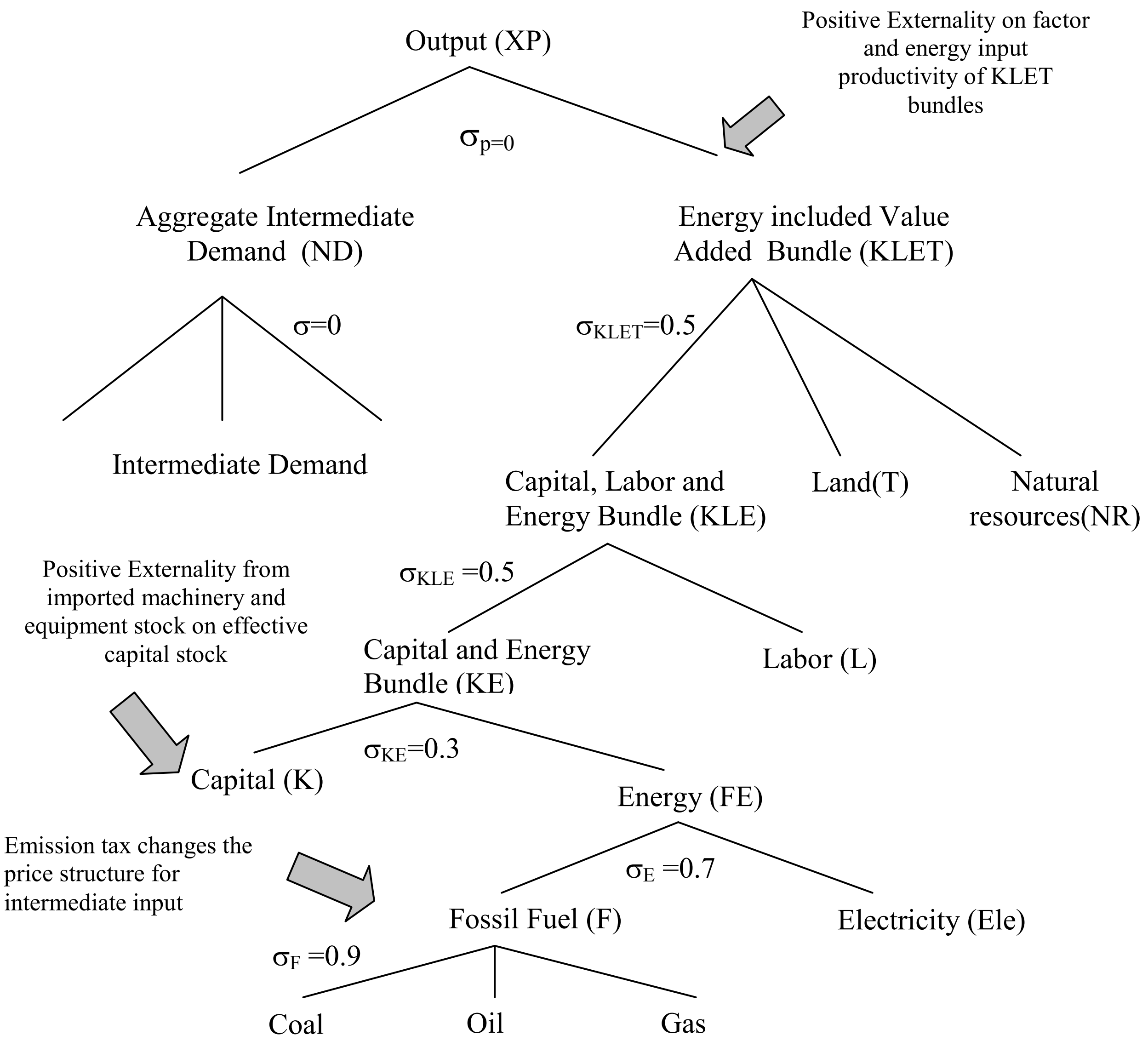
Fourthly, due to data constraint, excepts the inter-energy substitution, our model has not been able to capture the several other ways that can be used to reduce SO_2 emission, such as before-combustion coal cleaning technologies, which decrease the sulfur content ratio of the coal, the cleaner combustion technologies, which change the emission effluent ratio of the energies and finally the end-of-pipe controlling measures, which can realize some important total emission reduction results at the end of the combustion procedures. Although the estimated emission coefficients might reflect some original contribution of the above-mentioned desulfur technologies, the simulation results from our dynamic recursive model actually mixed up the aspect of the emission abatement technique investment and their possible amelioration effect on environment, economy and employment into the pure production section. Therefore, the emission levy rate suggested by our model might be exaggerated since the simulation is actually based on static emission control techniques and the potential economic cost from desulfur policy might be even smaller. This might be an interesting continuation for this model when the data on pollution controlling technique investment on sector level becomes available.

Finally, Given its limited oil and gas reserves, switching away from coal to the other cleaner energies means China needs to greatly increase her oil imports in recent years and to try to expand natural gas supply both domestically and from abroad. According to the International Energy Agency (IEA) and the Chinese government, in 2003, China's oil imports has accounted for over 30% of the country's total annual commercial energy supply, and China had since replaced Japan and become the world's second largest consumer of crude oil after the US. IEA considered China to be the "main driver of global oil demand growth". 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, which will unavoidably make the supposedly inter-energy switching process more costly.

TABLE 11. SENSITIVITY TEST (OPEN+DESULFUR SCENARIO)

	Units	0.7-0.9 (Original assumption)	0.5-0.7 (Moderately low elasticity)	0.3-0.5 (Very low elasticity)
1. Macroeconomic factors				
Real GDP	10^9US$	1520.10	1511.39	1503.02
Aggregate output	10^9US$	3909.08	3875.90	3848.44
Industry	10^9US$	2474.91	2453.97	2425.77
Export	10^9US$	515.70	521.05	516.06
Import	10^9US$	565.62	535.60	532.79
Real disposable income	10^9US$	1253.77	1251.13	1247.50
Per capita	US$	952.57	950.56	947.80
2. SO_2 emission determinants:				
Scale effect	**K tons**	4383,39	4323.95	4274.00
Composition effect	**K tons**	666,01	531.37	191.34
Externality effect	**K tons**	-128,86	-127.45	-126.15
Technique effect	**K tons**	-2182,14	-2186.82	-2191.49
Substitution effect	**K tons**	-2776,88	-2581.15	-2192.80
Residual	**K tons**	-13.19	-11.38	-6.58
3. Energy consumption				
Total coal input	10^9 TCE	0.24	0.25	0.26
Industry	10^9 TCE	0.22	0.23	0.24
Total oil input	10^9 TCE	0.38	0.36	0.34
Industry	10^9 TCE	0.28	0.26	0.24
Total gas input	10^9 TCE	0.03	0.03	0.03
Industry	10^9 TCE	0.03	0.03	0.03
Total electricity input	10^{12} kwh	1517.19	1525.90	1428.80
Industry	10^{12} kwh	1285.88	1289.75	1195.88
4. Necessary emission tax evolution				
Emission tax (1997)	US$	0.00545	0.00545	0.00545
Emission tax (2000)	US$	0.028816	0.028816	0.028816
Emission tax (2001)	US$	0.30	0.57	0.92
Emission tax (2002)	US$	0.66	1.06	1.62
Emission tax (2003)	US$	1.09	1.68	2.48
Emission tax (2004)	US$	1.62	2.46	3.54
Emission tax (2005)	US$	2.25	3.37	4.75

APPENDIX 1. Production Nesting Structure



Energy by type (from most polluting to less polluting)

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 in consumption of different goods are obtained from Roland-Holst, D. and D. 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 follow the existing literatures.

The export demand elasticity for the textile, wearing apparels, leather products and electronic equipments are all supposed to be 6.0.

Export-externality elasticity is supposed to be 0.1 and the same for that of the imported equipments and machinery stock.

APPENDIX 3. The expected tariff reduction schedule in China (percents change from 2000)

Sectors	2000	2001	2002	2003	2004	2005
Paddy rice	100	80.94	46.96	46.96	32.32	32.322
Wheat	100	93.75	93.75	93.75	93.75	693.75
Cereal grains, n.e.s.	100	98.31	96.61	94.92	93.22	93.22
Vegetables and fruits	100	11.11	11.11	11.11	11.11	177.78
Oil seeds	100	88.98	77.97	66.95	55.93	55.93
Sugar cane and sugar beet	100	11.11	11.11	11.11	11.11	177.78
Plant-based fibers	100	11.11	11.11	11.11	11.11	177.78
Crops, n.e.s.	100	89.04	78.08	68.49	58.22	58.22
Bovine cattle, sheep and goats,	100	97.22	94.44	93.06	90.28	90.28
Animal products n.e.s.	100	97.22	94.44	93.06	90.28	90.28
Raw milk	100	90.99	81.98	72.97	63.96	63.96
Wool, silk-worm cocoons	100	90.99	81.98	72.97	63.96	63.96
Forestry	100	68.00	64.00	60.00	60.00	60.00
Fishing	100	68.00	64.00	60.00	60.00	60.00
Coal	100	90.48	85.71	83.33	83.33	80.95
Oil	100	76.32	76.32	76.32	76.32	76.32
Gas	100	76.32	76.32	76.32	76.32	76.32
Electricity	100	76.32	76.32	76.32	76.32	76.32
Other minerals	100	90.48	85.71	83.33	83.33	80.95
Bovine, sheep and horse meat	100	90.29	80.58	70.87	61.65	55.83
Other meat products	100	90.29	80.58	70.87	61.65	55.83
Vegetable oils and fats	100	90.29	80.58	70.87	61.65	55.83
Dairy products	100	90.29	80.58	70.87	61.65	55.83
Processed rice	100	90.29	80.58	70.87	61.65	55.83
Sugar	100	90.29	80.58	70.87	61.65	55.83
Other food products	100	90.29	80.58	70.87	61.65	55.83
Beverage and tobacco	100	84.82	69.65	54.47	39.30	38.13
Textiles	100	88.89	66.67	55.56	44.44	33.33
Wearing Apparel	100	83.33	83.33	66.67	50.00	50.00
Leather products	100	100.00	100.00	100.00	50.00	50.00
Wood products	100	80.43	63.04	50.00	39.13	36.96
Paper products and publishing	100	80.43	63.04	50.00	39.13	36.96
Chemical, rubber and plastic	100	93.75	87.50	81.25	75.00	68.75
Other mineral products	100	86.49	72.97	67.57	62.16	59.46
Ferrous metals	100	86.49	72.97	67.57	62.16	59.46
Other metals	100	86.49	72.97	67.57	62.16	59.46
Metal products	100	86.49	72.97	67.57	62.16	59.46
Motor vehicles and parts	100	84.00	68.00	58.00	48.80	41.20
Other transport equipment	100	76.19	76.19	73.81	71.43	71.43
Electronic equipment	100	66.67	33.33	24.24	24.24	24.24
Other machinery and equipment	100	80.00	62.50	55.00	52.50	52.50
Other Manufactures	100	93.75	87.50	81.25	75.00	68.75
Water	100	93.75	87.50	81.25	75.00	68.75
services and construction(11	100	90.00	80.00	65.07	50.00	50.00

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

APPENDIX 4. Model Specification

A. Model specification

1. **Production**

1.1 Top level of production nesting

$$ND_j = \alpha_j^{nd}\left(\frac{PX_j}{PND_j}\right)^{\sigma_j^p} XP_j$$

$$KLET_j = \alpha_j^{klet}\left(\frac{PX_j}{PKLET_j}\right)^{\sigma_j^p} XP_j$$

$$PX_j = (\alpha_j^{nd} PND_j^{1-\sigma_j^p} + \alpha_j^{klet} PKLET^{1-\sigma_j^p})^{(1/(1-\sigma_j^p))}$$

$$PP_j = PX_j(1+\xi^{tp}\tau_j^p)$$

1.2 Second level of production nesting: intermediate input and KLET bundle

$$AT_j = \begin{cases} \overline{AT}\left(\dfrac{XET_j}{XET_{j,-1}}\right)^{\eta}, & if \quad XET_j > XET_{j,-1} \quad and \quad j \in ip \\ 1, & if \quad E_j < E_{j,-1} \quad or \quad j \in np \end{cases}, \overline{AT} = 1$$

$$BT = \overline{BT}\left(\frac{XMT_{hp,t}}{\sum_{hp}\sum_{t=0}^{presnet} XMT_{hp,t}}\right)^{\psi}, if \quad \sum_{hp} XMT_{hp,T} > 0, \overline{BT} = 1$$

$$or$$

$$BT = \overline{BT},, if \sum_{hp} XMT_{hp,T} > 0$$

$$XAP_{nd,j} = a_j^{nd} ND_j$$

$$PND_j = \sum_{nd} a_j^{nd}(1+\tau_{nd,j}^{pc})PA_{nd,j}$$

$$TD_j = \alpha_j^{td}\left(\frac{PKLET_j}{RENT_j(1+\tau_j^{td})}\right)^{\sigma_j^{klet}} (\lambda_j^t \times AT_j)^{(\sigma_j^{klet}-1)} KLET_j$$

$$NRD_j = \alpha_j^{nrd}\left(\frac{PKLET_j}{PNR_j}\right)^{\sigma_j^{klet}} (\lambda_j^{nr} \times AT_j)^{(\sigma_j^{klet}-1)} KLET_j$$

$$KLE_j = \alpha_j^{kle}\left(\frac{PKLET_j}{PKLE_j}\right)^{\sigma_j^{klet}} KLET_j$$

$$PKLET_j = \left[\alpha_j^{td}\left(\frac{RENT_j(1+\tau_j^{td})}{\lambda_j^t \times AT_j}\right)^{1-\sigma_j^{klet}} + \alpha_j^{nrd}\left(\frac{PNR_j(1+\tau_j^{nrd})}{\lambda_j^{nr} \times AT_j}\right)^{1-\sigma_j^{klet}} + \alpha_j^{kle} PKLE_j^{1-\sigma_k^{klet}}\right]^{1/(1-\sigma_j^{klet})}$$

1.3 Third level of production nesting: labor demand and KLE bundle

$$LD_j = \alpha_j^{ld}\left(\frac{PKLE_j}{WAGE_j(1+\tau_j^{ld})}\right)^{\sigma_j^{kle}} (\lambda_j^l \times AT_j)^{(\sigma_j^{kle}-1)} KLE_j$$

$$KE_j = \alpha_j^{ke}\left(\frac{PKLE_j}{PKE_j}\right)^{\sigma_j^{kle}} KLE_j$$

$$PKLE_j = \left[\alpha_j^{ld}\left(\frac{WAGE_j(1+\tau_j^{ld})}{\lambda_j^l \times AT_j}\right)^{1-\sigma_j^{kle}} + \alpha_j^{ke}\left(PKE\right)^{1-\sigma_j^{kle}}\right]^{\frac{1}{1-\sigma_j^{kle}}}$$

1.4 Fourth level of production nesting: capital demand and energy bundle

$$KD_j = \alpha_j^{kd}\left(\frac{PKE_j}{rate_j(1+\tau_j^{kd})}\right)^{\sigma_j^{ke}} (\lambda_j^k \times AT_j \times BT)^{\sigma^{ke}-1} KE_j$$

$$ENE_j = \alpha_j^{ene}\left(\frac{PKE_j}{PENE_j}\right)^{\sigma_j^{ke}} KE_j$$

$$PKE_j = \left[\alpha_j^{kd}\left(\frac{RATE(1+\tau_j^{kd})}{\lambda_j^k \times AT_j \times BT}\right)^{\sigma_j^{ke}-1} + \alpha_j^{ene} PENE^{\sigma_j^{ke}-1}\right]^{\frac{1}{1-\sigma_j^{ke}}}$$

1.5 Fifth level of production nesting: electricity demand and fossil fuel bundle

$$ELE_j = \alpha_j^{ele}\left(\frac{PENE_j}{PA_{ele,j}(1+\tau_{ele,j}^{pc})}\right)^{\sigma_j^{ene}} (\lambda_j^{ele} \times AT_j)^{\sigma_j^{ene}-1} ENE_j$$

$$FUEL_j = \alpha_j^{fuel}\left(\frac{PENE_j}{PFUEL_j}\right)^{\sigma_j^{ene}} ENE_j$$

$$PENE_j = \left[\alpha_j^{ele}\left(\frac{PA_{ele}(1+\tau_{ele,j}^{pc})}{\lambda_j^{ele} \times AT_j}\right)^{\sigma_j^{ene}-1} + \alpha_j^{fuel} PFUEL^{\sigma_j^{ene}-1}\right]^{\frac{1}{1-\sigma_j^{ene}}}$$

1.6 Sixth level of production nesting: Fossil Fuel demand

$$FUEL_{f,j} = \alpha_j^f\left(\frac{PFUEL_j}{PA_{f,j}(1+\tau_{f,j}^{pc}+\upsilon_f t_{poll})}\right)^{\sigma_j^{fuel}} (\lambda_j^f \times AT_j)^{\sigma_j^{fuel}-1} FUEL_j$$

$$PFUEL_j = \left[\sum_f\left(\frac{\alpha_j^f PA_{f,j}(1+\tau_{f,j}^{pc}+\upsilon_f t_{poll})}{\lambda_j^f \times AT_j}\right)^{\sigma_j^{fuel}-1}\right]^{\frac{1}{1-\sigma_j^{fuel}}}$$

1.7 Commodity aggregation

$$PP_j = P_k$$

$$X_k = \sum_{j \in k} XP_j$$

2. Income distribution

2.1 Factor income

$$LY = \sum_j WAGE_j LD_j$$

$$KY = \sum_j RATE_j KD_j$$

$$TY = \sum_j RENT_j TD_j$$

$$NRY = \sum_j PNR_j NRD_j$$

2.2 Profit distribution

$$TR\,KE = \varphi_{k,e} KY$$

$$TR\,KH = \varphi_{k,h} KY$$

$$TRKF = \varphi k,f\, KY$$

2.3 Corporate income re-distribution

$$YE = \varphi_{k,e}\, TR\,KE + \overline{TR\,GE} + \overline{TR\,FE}.\overline{ER}$$

$$YDE = \left[(1 - \kappa_e)(YE - \overline{TR\,GE}) + \overline{TR\,GE}\right]$$

$$SE = seYDE$$

$$TR\,EH = \varphi_{e,h} YDE$$

$$TR\,EF = \varphi_{e,f} YDE$$

2.4 Household income distribution

$$YH = LY + TY + NRY + \mathrm{TR}\,KH + \mathrm{TR}\,EH + \overline{\mathrm{TR}\,GH} + \overline{\mathrm{TR}\,FH}.\overline{ER}$$

$$YDH = (1 - \xi^h \kappa_h)(YH - \overline{\mathrm{TR}\,GH}) + \overline{\mathrm{TR}\,GH}$$

$$TRHF = \varphi_{h,f} YDH$$

3. Domestic final demand

3.1 Household's demand structure

$$SH = sh \times YDH$$

$$XAH_k = pop\theta_k + \frac{\mu_k}{\left(1+\tau_k^{hc}\right)PA_k}\left((1-\phi_{k,f} - sh)YDH - \sum_{kk}(1+\tau_{kk}^{hc})PA_{kk}\, pop\theta_{kk}\right)$$

$$CPI = \frac{\sum_k (1+\tau_k^{hc})PA_k XAH_{k,0}}{\sum_k \left(1+\tau_{k,0}^{hc}\right)PA_{k,0} XAH_{k,0}}$$

3.2 Government final goods expenditure

$$XAG_k = a_k^g \overline{XG}$$

$$YG = \sum_k \left(XAG_k.(1+\tau_k^{gc})PA_k\right)$$

$$PG = \frac{YG}{\overline{\overline{XG}}} = \sum_k a_k (1+\tau_k^{gc})PA_k$$

3.3 Exports of international trade and transport services

$$XATRDMGk = a_k^{trdmg}\overline{XTRDMG}$$

$$YTRDMG = \sum_k (XATRDMG_k(1+\tau_k^{trdmgc})PA_k)$$

$$PTRDMG = \frac{YTRDMG}{\overline{\overline{XTRDMG}}} = \sum_k a_k^{trdmgc}(1+\tau_k^{trdmgc})PA_k$$

3.4 Investment

$$XAINV_k = a_k^{inv} XINV$$

$$PINV = \sum_k a_k^{inv}(1+\tau_k^{invc})PA_k$$

$$INV = PINV.XINV$$

4. Trade

4.1 Top level Armington nesting

$$XA_k = \sum_j XAP_{k,j} + XAH_k + XAG_k + XAINV_k + XATRDMG_k$$

$$XDD_k = \alpha_k^{dd} \left(\frac{PA_k}{PDD_k} \right)^{\sigma_k^c} XA_k$$

$$XMT_k = \alpha_k^{mt} \left(\frac{PA_k}{PMT_k} \right)^{\sigma_k^c} XA_k$$

$$PA_k = \left[\alpha_k^{dd} PDD_k^{1-\sigma_k^c} + \alpha_k^{mt} PMT_k^{1-\sigma_k^c} \right]^{\frac{1}{1-\sigma_k^c}}$$

4.2 Second level Armington nesting

$$PM_{r,k} = \overline{ER}.\overline{WMP_{r,k}}(1 + \tau_{r,k}^m)$$

$$XM_{r,k} = \alpha_{r,k}^m \left(\frac{PMT_k}{PM_{r,k}} \right)^{\sigma_k^m} XMT_k$$

$$PMT_k = \left[\sum_r \alpha_{r,k}^m PM_{r,k}^{1-\sigma_k^m} \right]^{\frac{1}{1-\sigma_k^m}}$$

4.3 Top level of CET nesting

$$PE_{k,r}(1 + \tau_{k,r}^x) = \overline{ER}.WPEV_{k,r}$$

$$XDS_k = \gamma_k^{ds} \left(\frac{PDS_k}{P_k} \right)^{\sigma_k^p} X_k$$

$$XET_k = \gamma_k^{et} \left(\frac{PET_k}{P_k} \right)^{\sigma_k^p} X_k$$

$$P_k = \left[\gamma_k^{ds} PDS_k^{1+\sigma_k^p} + \gamma_k^{et} PET_k^{1+\sigma_k^p} \right]^{\frac{1}{1+\sigma_k^p}}$$

4.4 Second level of CET nesting

$$XE_{k,r} = \gamma_{k,r}^x \left(\frac{PE_{k,r}}{PET_k} \right)^{\sigma_k^x} XET_k$$

$$PET_k = \left[\sum_r \gamma_{k,r}^x PE_{k,r}{}^{1+\sigma_k^x} \right]^{\frac{1}{1+\sigma_k^x}}$$

$$ED_{k,r} = \alpha_{k,r}^e \left(\frac{\overline{WPE}_{k,r}}{WPEV_{k,r}} \right)^{\eta_{k,r}^e} \quad \text{if } \eta_{k,r}^e \neq \infty \text{ (Large country hypothesis)}$$

$$WPEV_{k,r} = \overline{WPE}_{k,r} \text{ if } \eta_{k,r}^e = \infty \text{ (Small country hypothesis)}$$

5. Market Equilibrium

5.1 Good market equilibrium

$$XDD_k = XDS_k$$

5.2 Factor market equilibrium

a. Labor Market

$$LS = \alpha^{ls} \left(\frac{ewage}{PLEV} \right)^{\omega^l}$$

$$LS = \sum_j LD_j$$

$$wage_j = \phi_j^l ewage$$

b. Capital market

$$TKS^e = \overline{BT} \left(1 + \frac{\sum_{hp} XMT_{hp}}{\sum_{hp} \sum_{t=0}^{present} XMT_{hp,t}} \right)^{\psi} TKS$$

$$KS_j = \gamma_j^k \left(\frac{rate_j}{PTK} \right)^{\omega^k} TKS^e$$

$$PTK = \left[\sum_j \gamma_j^k rate_j{}^{1+\omega^k} \right]^{\frac{1}{1+\omega^k}}$$

$$KS_j = KD_j$$

c. Land Market

$$TS_j = \gamma_j^t \left(\frac{rent_j}{PLAND} \right)^{\omega^t} LAND$$

$$PLAND = \left[\sum_j \gamma_j^t rent_j^{1+\omega^t} \right]^{\frac{1}{1+\omega^t}}$$

$$TS_j = TD_j$$

d. Specific Natural Resource Market

$$NRS_j = \gamma_j^{nr} \left(\frac{PNR_j}{PLEV} \right)^{\omega^{nr}}$$

$$NRD_j = NRS_j$$

6. Macro Closure

6.1 Government Account

$$\begin{aligned}
YG = & \underbrace{\sum_k \sum_j \tau_{k,j}^{pc} PA_k XAP_{k,j}}_{\text{Sale tax on intermeidate consumption}} + \underbrace{\sum_h \tau_k^{hc} PA_k XAH_k}_{\text{Household consumption tax}} + \underbrace{\sum_k \tau_k^{gc} PA_k XAG_k}_{\text{Government consumption tax}} \\
& + \underbrace{\sum_k \tau_k^{invc} PA_k XAINV_k}_{\text{Investment consumption tax}} + \underbrace{\sum_k \sum_r \tau_{k,r}^{x} PE_{k,r} XE_{k,r}}_{\text{export tax}} + tariff + \underbrace{\sum_j \tau_j^{pp} PX_j XP_j}_{\text{production tax}} \\
& + \underbrace{\kappa^h (YH - \mathrm{TR}\, GH)}_{\text{Household's income tax}} + \underbrace{\kappa^e (YE - \mathrm{TR}\, GE)}_{\text{Entreprise's income tax}} + \underbrace{\sum_j \tau_j^{ld} wage_j LD_j}_{\text{Labor factor tax}} + \underbrace{\sum_j \tau_l^{kf} rate_j KD_j}_{\text{Capital factor tax}} \\
& + \underbrace{\sum_j \tau_j^{td} rent_j TD_j}_{\text{Land tax}} + \underbrace{\sum_j \tau_j^{nrd} PNR_j NRD_j}_{\text{Specific natural resource tax}} + \underbrace{\sum_j .t_{poll} SO_{2\,j}}_{\text{Emission tax}} + \underbrace{\overline{ER}.\overline{\mathrm{TR}\, FG}}_{\text{Transfer from Foreign countries}}
\end{aligned}$$

$$tariff = \sum_r \sum_k \tau_{r,k}^{m} WPM_{r,k} XM_{r,k}$$

$$EXPG = YG + \overline{TR\,GH} + \overline{TR\,GE} + \overline{TR\,GF}.\overline{ER}$$

$$SG = YG - EXPG$$

$$\overline{RSG} = SG / PLEV$$

6.2 Investment account

$$INV = SH + SG + SE + \overline{SF}.\overline{ER}$$

6.3 Aggregate price index

$$PLEV = \frac{\sum_k PA_k XA_{k,0}}{\sum_k PA_{k,0} XA_{k,0}}$$

6.4 Balance of payment

$$\begin{aligned} Bop = & \sum_k \sum_r \overline{WPE_{k,r}} XE_{k,r} + Y\,\mathrm{TR}\,DMG + \overline{\mathrm{TR}\,FG} + \overline{\mathrm{TR}\,FH} + \overline{\mathrm{TR}\,FE} + \overline{SF} \\ & - \sum_r \sum_k \overline{WPM_{r,k}} XM_{r,k} - \frac{\mathrm{TR}\,HF + \mathrm{TR}\,EF + \mathrm{TR}\,KF}{\overline{ER}} - \overline{\mathrm{TR}\,FG} \\ & = 0 \end{aligned}$$

7. Macroeconomic identity

$$\begin{aligned} GDPMP = & \sum_k (1+\tau_k^{hc}) PA_k XAH_k + \sum_k (1+\tau_k^{gc}) PA_k XAG_k + \sum_k (1+\tau_k^{invc}) PA_k XAINV_k \\ & + ER \sum_k \sum_r \overline{WPE_{k,r}} XE_{k,r} - \sum_k \sum_r PM_{r,k} XM_{r,k} \end{aligned}$$

$$\begin{aligned} RGDPMP = & \sum_k (1+\tau_{k,0}^{hc}) PA_{k,0} XAH_k + \sum_k (1+\tau_{k,0}^{gc}) PA_{k,0} XAG_k + \sum_k (1+\tau_{k,0}^{invc}) PA_{k,0} XAINV_k \\ & + ER_0 \sum_k \sum_r \overline{WPE_{k,r,0}} XE_{k,r} - \sum_k \sum_r PM_{r,k,0} XM_{r,k} \end{aligned}$$

$$PGDPMP = GDPMP / RGDPMP$$

$$GDPFC = \sum_j wage_j LD_j + \sum_j rate_j KD_j + \sum_j rent_j TD_j + \sum_j PNR_j NRD_j$$

$$RGDPFC = \sum_j wage_{j,0} LD_j + \sum_j rate_{j,0} KD_j + \sum_j rent_{j,0} TD_j + \sum_j PNR_{j,0} NRD_j$$

$$PGDPFC = GDPFC / RGDPFC$$

8. Emission equations

$$SO_{2\,f,j} = \overline{\upsilon_f} XAP_{f,j}$$

$$SO_{2\,j} = \sum_f SO_{2\,f,j}$$

$$TSO_2 = \sum_j SO_{2\,j}$$

9. Growth equations

$$RGDPMP = (1 + g^{y})RGDPMP_{-1}$$

10. Dynamic equations for exogenous variables

$$\lambda^{l}_{ip} = \left(1 + \overline{\gamma^{kle}} + \chi^{l}_{ip}\right)\lambda^{l}_{ip,-1}$$

$$\lambda^{k}_{ip} = \left(1 + \overline{\gamma^{kle}} + \chi^{k}_{ip}\right)\lambda^{k}_{ip,-1}$$

$$\lambda^{f}_{ip} = \left(1 + \overline{\gamma^{kle}} + \chi^{f}_{ip}\right)\lambda^{f}_{ip,-1}$$

$$\lambda^{ele}_{ip} = \left(1 + \overline{\gamma^{kle}} + \chi^{ele}_{ip}\right)\lambda^{ele}_{ip,-1}$$

$$\lambda^{l}_{np} = \left(1 + \overline{\gamma^{l}}\right)\lambda^{l}_{np,-1}$$

$$\lambda^{k}_{np} = \left(1 + \overline{\gamma^{k}}\right)\lambda^{k}_{np,-1}$$

$$\lambda^{f}_{np} = \left(1 + \overline{\gamma^{f}}\right)\lambda^{f}_{np,-1}$$

$$\lambda^{ele}_{np} = \left(1 + \overline{\gamma^{ele}}\right)\lambda^{ele}_{np,-1}$$

$$\overline{\lambda^{t}_{j}} = \overline{\lambda^{t}_{j,-1}}$$

$$\overline{\lambda^{nr}_{j}} = \overline{\lambda^{nr}_{j,-1}}$$

$$pop = (1 + \overline{g^{pop}})pop_{-1}$$

$$LAND = (1 + \overline{g^{t}})LAND_{-1}$$

$$\alpha^{ls} = (1 + \overline{g^{l}})\alpha^{ls}_{-1}$$

$$\gamma^{nr}_{j} = (1 + \overline{g^{nr}})\gamma^{nr}_{j,-1}$$

$$K\,sup = (1 - \delta)K\,sup_{-1} + INV$$

$$TKS = (TKS_{0} / K\,sup_{0})K\,sup$$

B. Model Variables and parameters

1. Indices used in the model

j	Production activities
k (or kk)	Commodities
f	Fossil fuel energies
ele	electricity

nd	Intermediate consumptions
np	Exogenous factor productivity growth sectors
ip	Endogenous factor productivity growth sector
hp	Machinery and equipment industrial sectors

2. Model variables and parameters

a. Endogenous variables

Production	
ND_j	Demand for aggregate intermediate demand bundle
$KLET_j$	Demand for value added and energy input bundle
PX_j	Unit cost of production
PP_j	Producer price
AT_j	Export externality productivity shifter
BT	Productivity shifter coming from the externality of Imported machinery and equipment
$XAP_{nd,j}$	Intermediate demand for goods and services
PND_j	Price of aggregate intermediate demand bundle
KLE_j	Demand for capital-labor-energy bundle
TD_j	Demand for aggregate land bundle
NRD_j	Demand for sector-specific resource
$PKLET_j$	Price of value added and energy input bundle
LD_j	Demand for labor factor
KE_j	Demand for capital/energy input bundle
$PKLE_j$	Price of capital-labor-energy bundle
KD_j	Demand capital factor
ENE_j	Demand for aggregate energy bundle
PKE_j	Price of capital and aggregate energy input bundle
ELE_j	Demand for electricity input
$FUEL_j$	Demand for aggregate fossil fuel energy bundle
$PENE_j$	Price for aggregate energy bundle
$XAP_{f,j}$	Demand for fossil fuel energy input
$PFUEL_j$	Price for aggregate fossil fuel energy input bundle
P_k	Aggregate producer price of commodity *k*
XP_j	Aggregate sector output (of activity *j)*
Income distribution	
LY	Aggregate net labor remuneration
KY	Aggregate after-tax capital income
TY	Aggregate after-tax land income
NRY	Aggregate after-tax income from sector-specific resource
TRKE	Capital income transferred to enterprises
TRKH	Capital income transferred to households
TRKF	Capital income transferred abroad
YE	Corporate income
YDE	Corporate disposable income
SE	Corporate retained earnings
TREH	Corporate earnings transferred to households
TREF	Corporate earnings transferred abroad
YH	Aggregate household income
YDH	Disposable income net of taxes and transfers
TRHF	Household transfers abroad
Domestic demand variables	
SH	Household savings
XAH_k	Household demand for goods and services
CPI	Household-specific consumer price index
XAG_k	Government final demand for goods and services
YG	Government final demand aggregate expenditure level

PG	Aggregate price for total government final demand
$XATRDMG_k$	Demand for export of trade and transportation services
$YTRDMG$	Export of trade and transportation services demand aggregate expenditure level
$PTRDMG$	Aggregate price of total demand for export of trade and transportation services
$XAINV_k$	Investment final demand for goods and services
$PINV$	Aggregate price for total investment final demand
INV	Investment final demand aggregate expenditure level

Trade

XA_k	Economy-wide demand for Armington good
XDD_k	Domestic demand for domestic production
XMT_k	Domestic demand for aggregate imports
PA_k	Price of Armington good
$PM_{r,k}$	Domestic tariff-inclusive price of imports by region of origin
$XM_{r,k}$	Sectoral import volume by region of origin
PMT_k	Price of aggregate import bundle
$PE_{k,r}$	Producer price of exports by region of destination
XDS_k	Domestic output sold domestically
XET_k	Aggregate export supply
X_k	Aggregate output
$XE_{k,r}$	Export supply by region of destination
PET_k	Price of aggregate exports
$ED_{k,r}$	Demand for exports by region of destination
$WPEV_{k,r}$	Price of the export demand by region of destination (large country hypothesis)

Market equilibrium

Goods market equilibrium

PDD_k	Price of domestic goods sold domestically

Factor market equilibrium

LS	Labor supply
$ewage$	Equilibrium wage rate
$wagej$	Sector specific wage rate
TKS^e	Effective aggregate capital supply
KS_j	Sectoral capital supply
PTK	Economy-wide aggregate rate of return to capital
$rate_j$	Sectoral rate of return to capital by type
TS_j	Sectoral land supply
$PLAND$	Economy-wide aggregate rate of return to land
$rent_j$	Sectoral rate of return to land
NRS_j	Sectoral supply of sector-specific factor
PNR_j	Price of sector-specific factor

Macro Closure

Government account

YG	Government total revenue
$tariff$	Government tariff revenue
$EXPG$	Government total expenditure
SG	Government savings

Investment account

INV	Total expenditure on investment

Aggregate price index

$PLEV$	Aggregate price level

Macroeconomic identity

$GDPMP$	Nominal GDP at market price
$RGDPMP$	Real GDP at market price

PGDPMP	GDP at market price deflator
GDPFC	Nominal GDP at factor cost
RGDPFC	Real GDP at factor cost
PGDPFC	GDP at factor cost deflator
Emission	
$SO_{2f,j}$	Emission of SO_2 from each fossil fuel energy f combusted in sector j
SO_{2j}	Emission of SO_2 from sector j
TSO_2	Total emission of SO_2

b. Key model elasticities

Production elasticities	
σ^{p}_{j}	Substitution elasticity between intermediate consumption and capital-labor-energy-land-natural resource bundles
σ^{klet}_{j}	Substitution elasticity between capital-labor-energy bundle and land, natural resource
σ^{kle}_{j}	Substitution elasticity between capital-energy bundle and labor
σ^{ke}_{j}	Substitution elasticity between capital and energy bundles
σ^{ene}_{j}	Substitution elasticity between electricity-fossil fuel energy bundles
σ^{fuel}_{j}	Substitution elasticity between the fossil fuels
η	Export externality elasticity with respect to export growth
ψ	Import externality elasticity with respect to growth in imported machinery stocks
Demand elasticities	
μ_k	Based household income elasticities
Trade elasticities	
σ^{c}_{k}	Armington elasticities between domestic and aggregate import demand
σ^{m}_{k}	Armington elasticities between import demand across different origins
σ^{p}_{k}	Top-level transformation elasticity between the domestic market and aggregate exports
σ^{x}_{k}	Transformation elasticity of exports across different destinations
$\eta^{e}_{k,r}$	Price elasticity of World demand for export by regions of destinations
Factor market elasticities	
ω^{l}	Labor supply elasticity with respect to wage level
ω^{k}	Transformation of capital across different sectors
ω^{l}	Transformation of land across different sectors
ω^{nr}_{j}	Natural resource supply elasticity with respect to price
Emission factors	
υ_f	Energy specific emission rate

c. Calibrated parameters

Production	
α^{nd}_{j}	CES share parameter for intermediate consumption bundle
α^{klet}_{j}	CES share parameter for capital-labor-energy-land-natural resource bundle
$a_{nd,j}$	Leontief coefficients for intermediate demand
α^{ld}_{j}	CES share parameter for land demand
α^{nrd}_{j}	CES share parameter for sectoral specific natural resource demand
α^{kle}_{j}	CES share parameter for capital-labor-energy bundle
α^{ld}_{j}	CES share parameter for labor demand
α^{ke}_{j}	CES share parameter for capital-energy bundle
α^{kd}_{j}	CES share parameter for capital demand
α^{ene}_{j}	CES share parameter for energy bundle
α^{ele}_{j}	CES share parameter for electricity demand
α^{fuel}_{j}	CES share parameter for fossil fuel energy bundle

$\alpha^{f}{}_{j}$	CES share parameter for fossil fuel demand
Saving behaviors	
sh	Household savings rate
se	Entreprise savings rate
Income distribution parameters	
$\varphi_{k,e}$	Enterprise share of after-tax capital income
$\varphi_{k,h}$	Household share of after-tax capital income
$\varphi_{k,f}$	Rest of world share of after-tax capital income
$\varphi_{e,h}$	Household share of after-tax enterprise income
$\varphi_{e,f}$	Rest of world share of after-tax capital income
$\varphi_{h,f}$	Rest of world share of after-tax household income
Demand parameters	
θ_k	Household minimum consumption parameter
$a^{g}{}_{k}$	Commodity share parameter for government consumption
$a^{inv}{}_{k}$	Commodity share parameter for investment consumption
$a^{trdmg}{}_{k}$	Commodity share parameter for exported trade and transportation services
Trade parameters	
$\alpha^{dd}{}_{k}$	Domestic share parameter in top-level Armington CES
$\alpha^{mt}{}_{k}$	Import share parameter in top-level Armington CES
$\alpha^{m}{}_{r,k}$	Regional share parameter in second-level Armington CES
$\alpha^{e}{}_{k,r}$	Export demand shift parameter by region of destination
$\gamma^{ds}{}_{k}$	Domestic share parameter in top-level CET
$\gamma^{et}{}_{k}$	Export share parameter in top-level CET
$\gamma^{x}{}_{k,r}$	Regional share parameter in second-level CET
Factor market parameters	
$\phi^{l}{}_{j}$	Inter-sectoral wage differential parameters
α^{ls}	Labor supply shift parameter
$\gamma^{k}{}_{j}$	Capital allocation share parameters between sectors
$\gamma^{l}{}_{j}$	Land allocation share parameters between sectors
$\gamma^{nr}{}_{j}$	Specific natural resource allocation share parameter between sectors

d. Exogenous variables

Growth factors	
g^{y}	Real GDP growth rate
$Ksup$	Aggregate non-normalized capital stock
TKS	Aggregate normalized capital stock
$LAND$	Aggregate land supply
pop	Total population
g^{pop}	Population growth rate
g^{ls}	Labor supply growth rate
g^{nr}	Natural resource supply growth rate
g^{t}	Land supply growth rate
δ	Capital depreciation rate
γ^{kle}	Capital, labor and energy factor productivity growth factor (endogenous factor growth sectors)
$\chi^{l}{}_{ip}$	Labor productivity discrepancy shifter (endogenous factor growth sectors)
$\chi^{k}{}_{ip}$	Capital productivity discrepancy shifter (endogenous factor growth sectors)
$\chi^{f}{}_{ip}$	Fossil fuel productivity discrepancy shifter (endogenous factor growth sectors)
$\chi^{ele}{}_{ip}$	Electricity productivity discrepancy shifter (endogenous factor growth sectors)
$\gamma^{l}{}_{np}$	Labor factor productivity growth factor (exogenous factor growth sectors)
$\gamma^{k}{}_{np}$	Capital factor productivity growth factor (exogenous factor growth sectors)
$\gamma^{f}{}_{np}$	Fossil fuel energy factor productivity growth factor (exogenous factor growth sectors)

γ^{ele}_{np}	Capital, labor and energy factor productivity growth factor (endogenous factor growth sectors)
λ^{l}_{ip}	Labor productivity for sectors with endogenous factor productivity growth shifter
λ^{k}_{ip}	Capital productivity for sectors with endogenous factor productivity growth shifter
λ^{f}_{ip}	Fuel energy productivity for sectors with endogenous factor productivity growth shifter
λ^{ele}_{ip}	Electricity productivity for sectors with endogenous factor productivity growth shifter
λ^{l}_{np}	Labor productivity for sectors with exogenous factor productivity growth shifter
λ^{k}_{np}	Capital productivity for sectors with exogenous factor productivity growth shifter
λ^{f}_{np}	Fuel energy productivity for sectors with exogenous factor productivity growth shifter
λ^{ele}_{np}	Electricity productivity for sectors with exogenous factor productivity growth shifter
λ^{t}_{j}	Land productivity growth factor
λ^{nr}_{j}	Natural resource productivity growth factor
Trade price	
$\overline{WPE_{k,r}}$	Export price index of competitors
$WPM_{r,k}$	World price of import by region of origin
ER	Exchange rate
Fiscal variables	
RSG	Real government saving
XG	Aggregate government consumption in volume
τ^{p}_{j}	Producer's tax
$\tau^{pc}_{k,j}$	Producer's intermediate consumption tax
τ^{ld}_{j}	Labor input tax
τ^{kd}_{j}	Capital input tax
τ^{td}_{j}	Land input tax
τ^{nrd}_{j}	Sectoral specific natural resource input tax
ξ^{h}	Household's income tax adjustment factor
κ^{h}	Household's income tax
κ^{e}	Enterprise income tax
$\tau^{x}_{k,r}$	Export tax by region of destination
$\tau^{m}_{r,k}$	Import tariff by region of origin
τ^{hc}_{k}	Household consumption tax
τ^{gc}_{k}	Government consumption tax
τ^{invc}_{k}	Investment final consumption tax
τ^{trdmg}_{k}	Tax on export of trade and transportation services
t_{poll}	Emission tax
$TRGH$	Government transfer to households
$TRGE$	Government transfer to enterprises
Miscellaneous exogenous variables	
$TRGF$	Government transfer to foreign countries
$TRFG$	Foreign transfer received by government
$TRFH$	Foreign transfer to household
$TRFE$	Part of enterprise income coming from foreign countries
SF	Foreign saving
$XTRDMG$	Aggregate exports of transportation service in volume

e. Key model elasticities

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Emission factors	
υ_f	Energy specific emission rate

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$\alpha^{ld}{}_{j}$	CES share parameter for labor demand
$\alpha^{ke}{}_{j}$	CES share parameter for capital-energy bundle
$\alpha^{kd}{}_{j}$	CES share parameter for capital demand
$\alpha^{ene}{}_{j}$	CES share parameter for energy bundle
$\alpha^{ele}{}_{j}$	CES share parameter for electricity demand
$\alpha^{fuel}{}_{j}$	CES share parameter for fossil fuel energy bundle
$\alpha_{f,j}$	CES share parameter for fossil fuel demand
$\overline{AT}$	Original export externality's productivity shifter factor
$\overline{BT}$	Original import externality's productivity shifter factor
Saving behaviors	
sh	Household savings rate
sc	Enterprise savings rate
Income distribution parameters	
$\varphi_{k,e}$	Enterprise share of after-tax capital income
$\varphi_{k,h}$	Household share of after-tax capital income
$\varphi_{k,f}$	Rest of world share of after-tax capital income
$\varphi_{e,h}$	Household share of after-tax enterprise income
$\varphi_{e,f}$	Rest of world share of after-tax capital income
$\varphi_{h,f}$	Rest of world share of after-tax household income

Demand parameters

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$a^g{}_k$	Commodity share parameter for government consumption
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$\gamma^t{}_j$	Land allocation share parameters between sectors
$\gamma^{nr}{}_j$	Specific natural resource supply shifter parameter

REFERENCE

Anderson, D. and W. Cavendish (2001). Dynamic Simulation and Environmental Policy Analysis: Beyond Comparative Statics and the Environmental Kuznets Curve, *Oxford Economic Papers*, vol. 53, pp721-746.

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

Antweiler, W., B. R. Copeland and M.S. Taylor (2001). "Is Free Trade Good for The Environment?", *American Economic Review,* Vol. 91, No.4, Sept, pp 877-908.

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.

Bovenberg, A. L., (1999). Green tax reforms and the double dividend: an updated reader's guide, *International Tax and Public Finance*, Vol. 6, pp. 421-443.

Bovenberg, A. L., and F. van der Ploeg. (1994). Environmental policy, public finance and the labour market in a second-best workd, *Journal of Public Economics*, Vol. 55(3). pp. 349-390.

Bovenberg, A. L., and F. van der Ploeg. (1998a). Consequences of environmental tax reform for unemployment and welfare, *Environmental and Resource Economics*, Vol. 12(2). pp. 137-150.

Bovenberg, A. L., and F. van der Ploeg. (1998b). Tax reform, structural unemployment, and the environment, *Scandinavian Journal of Economics*, Vol. 100(3). pp. 593-610.

Bovenberg, A. L., and R. A. de Mooij. (1994). Environmental levies and distortionary taxation, *American Economic Review*, Vol. 84(4). pp. 1085-1089.

Bovenberg, A. L., and R. A. de Mooij. (1997). Environmental tax reform and endogenous growth, *Journal of Public Economics*, Vol. 63(2). pp. 207-237.

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 in OECD Countries,* OECD, 1999, pp233-257.

Carraro, C., M. Galeotti and M. Gallo, (1996). Environmental taxation and unemployment: Some evidence on the 'double dividend hypothesis' in Europe. *Journal of Public Economics*, vol. 62, pp. 141-181.

Copeland, B. and M. S. Taylor (1997). *A Simple Model of Trade, Capital Mobility and the Environment*, NBER, No. 5898.

Copeland, B. and M. S. Taylor, (1994). "North-South Trade and the Environment", *The Quarterly Journal of Economics*, August, 1994, pp755-787.

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

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.

Goulder, L. H., (1995). Environmental taxation and "double-dividend": a reader's guide, International Tax and Public Finance, Vol. 2(2). pp. 157-183.

Grether, J. M. and J. de Melo, Commerce, environnement et relations Nord-sud: les enjeux et quelques tendances récentes, Revue de Economie du Développement, *Revue d'économie de développement,* Vol. 4, pp. 69-102.

Grossman, G. (1995). Pollution and growth: What do we know? Goldin and Winter (eds.). *The Economics of Sustainable Development*, Cambridge University Press, 1995.

Hettige, H., R. E. B. Lucas and D. Wheeler (1992). "The Toxic Intensity of Industrial Production: Global Patterns, Trends, and Trade Policy", *American Economic Review*, Vol. 82, No. 2, pp478-481.

Kemfert, C., (1998). Estimated Substitution Elasticities of a Nested CES production funcion approch for Germany, *Energy Economics*, Vol. 20, pp249-264.

Kemfert, C., and H. Welsch, (2000). Energy-Capital-Labor Substituion and the Economic Effects of CO_2 Abatement: Evidence from Germany, *Journal of Policy Modeling*, Vol. 22(6). pp641-660.

Kumbaroglu, G. S., (2003). Environmental taxation and economic effects: a computable general equilibrium analysis for Turkey, *Journal of Policy Modeling*, Vol. 25, pp. 795-810.

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.

Lucas, R. E., B.D. Wheeler, and H. Hettige (1992). "Economic Development, Environmental Regulation and the International Migration of Toxic Industrial pollution : 1960-1988", P. Low (Ed). *International Trade and the Environment*, World Bank, Discussion paper No. 159, Washington, DC.

Mensbrugghe, D. V. D., D. Roland-Holst, S. Dessus and J. Beghin, (1998). The interface between growth, trade, pollution and natural resource use in China: evidence from an economy wide model, *Agricultural Economics,* vol. 19, no. 1-2, pp. 843-860.

Pethig, R. (1976). Pollution, Welfare, and Environmental Policy in the Theory of Comparative Advantage, *Journal of Environmental Economics and Management,* Vol. 2, pp160-169.

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

Rock, M. T., (1996). Pollution Intensity of GDP and Trade Policy: Can the World Bank Be Wrong?, *World Development*, Vol. 24, No. 3, pp. 471-479.

Rogrigo, G.C., and E. Thorbecke, (1997). Sources of Growth: A Reconsideration and General Equilibrium Application to Indonesia, *World Development*, Vol. 25, No. 10, pp1609-1625.

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.

Sinton, J. E., (2001). Accuracy and reliability of China's energy statistics, *China Economic Review*, vol. 12, pp. 373-383.

Tobey, J. A. (1990). The effect of domestic environmental policies on patterns of world trade: An empirical test, *Kyklos* 43 (2). 191-209.

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.