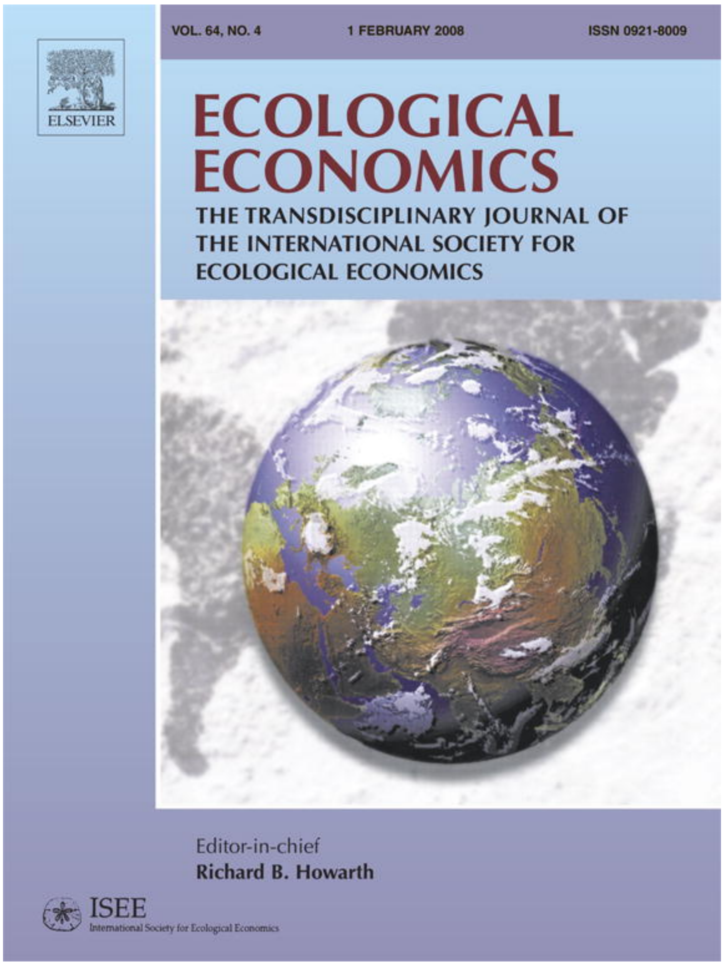
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ANALYSIS

Environmental impacts of China's WTO-accession☆

Haakon Vennemo[a,*], Kristin Aunan[b], Jianwu He[c], Tao Hu[d], Shantong Li[c], Kristin Rypd3al[b]

[a]ECON Analysis, P.O.Box 5, 0051 Oslo, Norway
[b]CICERO Center For International Climate and Environmental Research, Oslo, Norway
[c]Development Research Center of State Council, Beijing, China
[d]Policy Research Center for Environment and Economy of SEPA, Beijing, China

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ABSTRACT

China's accession to the WTO in 2001 completed the country's entry into the global economy. We investigate environmental implications of WTO-accession. There are several hypotheses in this area: The scale hypothesis says that production is scaled up and in turn, pollution increases. The technique hypothesis says that production methods become cleaner and pollution decreases. The composition hypothesis says that composition of industries changes and pollution reflects the new composition. We analyse the relative strength of the hypotheses by means of an environmental CGE-model, and in the case of air pollution find support for a composition effect in favour of clean industries. Thanks to the composition effect, emissions to air of greenhouse gases fall. Emissions of particles and SO_2 also fall, but emissions of NO_x and VOC rise. Since particle and SO_2-emissions fall we estimate that public health improves.

1. Introduction

China's accession to WTO in 2001 has spurred significant research. Ianchovichina and Martin (2001), Gilbert and Wahl (2002) and Hertel and Zhai (2006) investigate economic impacts for China of WTO accession. McKibbin and Tang (2000), Martin and Ianchovichina (2001) and Wang (2003) look at implications for third countries and for the WTO system itself. Both the China Quarterly (see Fewsmith, 2001) and China Economic Review (see Chun et al., 2001) have published special issues on WTO and China, and it has been the subject of books, for instance Panditchpakdi and Clifford (2002), Lardy (2002) and recently Bhattasali et al. (2004).

To our knowledge, however, the rich literature on China and WTO has not analysed environmental implications of China's WTO accession.[1] Yet the environmental implications are of major concern to stakeholders inside and outside China. The environmental implications of trade are at the heart of the globalisation

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* Corresponding author.
E-mail address: hve@econ.no (H. Vennemo).

[1] An exception is a number of reports commissioned by the China Council for International Cooperation for Environment and Development (CCICED), for example CCICED (2004). See http://www.iisd.org/trade/cciced/taskforce_documents.asp. Dean (2002) discusses implications of trade liberalisation in China 1987–95 on water pollution. A recent paper of He (2005) analyses the linkage between WTO accession, impacts on SO_2 and the cost of SO_2 abatement.

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debate, and with China the biggest source of SO_2 and second largest source of CO_2 in the world as well as the home of unique biological resources, changes to its environmental performance have global interest. Pessimists worry that WTO-accession will increase China's production of dirty industrial products. The argument is that environmental regulation in rich countries drives dirty industrial production to developing countries. With China in the WTO the process could accelerate. Another worry is that since WTO will push economic growth, opportunities for polluting consumption increase. On the other hand, optimists hope that WTO accession will improve the standard of technology invested in China, and efficient technology tends to pollute less.

The objective of our paper is to investigate air-related environmental implications of WTO-accession. We wish to assess the relative strength of the forces that pull in different directions and together shape the response to WTO accession. To do that we need a quantitative framework and we employ an environmental computable general equilibrium (CGE) model. An advantage of such a model is that it allows a comprehensive assessment of a cross-cutting policy change like WTO-accession. The model is based on micro foundations and complies with the input–output structure and overall constraints of the economy. That makes for consistent predictions built on first principles. The CGE-model is familiar tool for analysing economic consequences of WTO-accession, and is used for that purpose by Zhai and Li (2000), Gilbert and Wahl (2002), Hertel et al. (2004) and Hertel and Zhai (2006) among others. Our paper differs from these in its environmental focus.

2. Trading regime before accession

In order to analyse environmental implication of WTO-accession we first describe the trading regime prior to accession. Since 1986–87 China had two separate trading regimes (Naughton, 1996; Zhai and Li, 2000). One was the traditional, but increasingly reformed, ordinary trading regime. Despite reforms the ordinary regime was characterized by tariffs on more or less all industries and import quotas on important goods produced in agriculture and industry, for instance rice, wheat, petroleum and automobiles. Quotas in agriculture were motivated by the grain self-sufficiency policy of China.

The other trading regime was an export processing or export promotion regime, which was exempt from most tariffs and quotas. The export promotion regime comprised of exports with a high content of imported inputs. It had few linkages to the local economy and was located in special zones. By 1997 it accounted for half of all exports and imports. 1997 is the base year of our analysis.

The existence of two trading regimes, plus extensive import duty exemptions and widespread smuggling activities (World Bank, 1994, Bach et al., 1996; Fisman and Wei, 2004) meant that in some industries actual tariffs were substantially lower than nominal tariffs. In those industries quotas were the main trade barriers. In textiles, for example, the nominal tariff rate was 27.5% but the actual, effective rate only 0.2%. For apparel, China's main export earner before accession at a 64-industry disaggregation, the nominal rate was 41.8% and the actual rate 0.7%. In other industries there remained a significant effective tariff, for instance automobiles (32.6%), beverages (24.0%) and tobacco (10.6%).

Despite a complicated structure of tariffs, quotas and a dual trading regime, Table 1 indicates that net export patterns before accession broadly reflected China's comparative advantage. Labor intensive industries like apparel and textile, leather, social articles (mostly toys, sports and recreation equipment) were big export earners in 1997. Capital intensive industries like machinery and chemicals were big import spenders. Special equipment, another big import spender, includes capital equipment for agriculture, forestry and fishing.

Since WTO-accession exposes industries to international competition the main impact of accession is likely to be improved use of comparative advantage. WTO-accession also has an important regional dimension. Most trading industries in China are located in coastal provinces. On the expectation that trading industries expand following accession, coastal provinces may benefit more than inland provinces. That may increase regional disparity, which already is a serious social problem in China.

3. Trading regime after accession

Important changes in the trading framework following WTO-accession are presented Table 2. They form the drivers for our scenarios of air related environmental impacts of accession. The table also presents our answer to the counterfactual question what would have happened without WTO-accession. In the counterfactual we assume that China continues its grain self-sufficiency policy and import quotas grow 3% annually from 2000–2010. The first accession scenario considers the tariff reduction and quota elimination on industrial products that China offered in the final round of WTO-negotiation. The industry reduction rates of import tariffs are aggregated from the Harmonised Commodity Description and Coding System tariff schedules for the period 2000–2008 in the China–US agreement and weighted by the 1997 ordinary trade data.[2] In this scenario, import quotas for petroleum refining and automobiles are phased out and eliminated from 2005.

The second scenario focuses on agricultural trade liberalisation. After accession quota equivalent tariffs have been introduced to replace quotas on rice, wheat, corn, cotton, wool, vegetable oil and sugar. The tariffs are gradually reduced. Tariffs on other agricultural goods are also reduced.[3]

[2] The choice of actual trade data as aggregation weights is not innocuous. Hypothetical trade data in a free-trading regime would be the best, but is if course impossible. Since actual trade data incorporates adjustment to current trade distortions, driving down effective tariff rates as seen in Table 1, they tend to underplay the importance of removing distortions. Part of that gain is of course to make adjustments to trade distortions superfluous. An alternative to trade data as weights is to weigh by output data. That is not innocuous either since it is unreasonable that free trade will imply equal trading shares of all industries. How reasonable or unreasonable is unclear. Besides, output data also incorporates adjustment to trade distortions. We use trade data as weights since it was felt that it gives a degree of control of its implications on results. We acknowledge that it implies underestimation of trade gains.

[3] If imports of agricultural goods exceed 1.5% of domestic production, China is allowed by the WTO-agreement to introduce high tariffs above the 1.5% quota. In our scenarios imports of agricultural goods are lower than 15%.

Table 1 – Economic structure and market openness in China, 1997 (%)

	Net export (bn. Yuan)	Nominal tariff rate	Effective tariff rate
Rice	0.0	1.0	0.4
Wheat	−11.3	1.0	0.2
Corn	6.3	1.0	0.0
Cotton	−7.7	3.0	0.6
Other non-grain crops	12.8	4.6	5.7
Forestry	−2.6	28.6	8.3
Wool	−3.8	15.0	0.7
Other livestock	6.8	5.0	2.1
Fishing	2.5	0.8	0.5
Other agriculture	1.5	16.0	1.7
Coal mining	8.6	6.0	3.3
Crude oil	−22.8	1.5	1.0
Natural gas	2.2	6.0	0.0
Ferrous ore mining	−14.4	0.0	0.0
Non-ferrous ore mining	−4.9	0.0	0.0
Quarrying	4.8	8.1	0.9
Logging	−5.3	2.0	1.0
Vegetable Oil	−10.3	17.0	5.3
Grain mill and forage	−7.9	4.7	4.4
Sugar	−0.8	30.0	9.5
Processed food	42.4	23.2	3.7
Beverage	7.5	60.2	24.0
Tobacco	3.3	49.1	10.6
Textile	104.5	27.5	0.2
Apparel	156.2	41.8	0.7
Leather	61.4	35.5	0.3
Sawmills	−5.1	10.4	1.7
Furniture	27.9	38.3	9.0
Paper	−28.0	10.3	3.1
Printing	−1.2	26.3	2.1
Social article	87.6	3.1	1.0
Petroleum refining	−19.6	8.7	4.8
Chemicals	−77.8	10.8	3.0
Medicine	8.5	10.9	7.2
Chemical fibers	−17.4	15.5	1.0
Rubber	25.4	13.9	2.2
Plastic	17.4	24.5	1.9
Build materials	23.9	20.8	3.6
Primary iron and steel	−17.5	8.1	2.0
Non-ferrous metals	−13.1	7.1	0.9
Metal products	36.4	13.1	2.4
Machinery	−41.0	11.3	4.2
Special equipment	−82.9	15.0	2.6
Automobile	−7.6	50.7	32.6
Oth. Transport equipment	−5.8	5.2	1.3
Electric machinery	42.2	17.9	3.1
Electronics	25.2	11.8	2.1
Instruments	12.3	12.5	2.3
Other manufacturing	9.6	38.9	0.9
Electricity production	3.8	0.0	0.0
Gas	0.0	6.0	0.1
Water	0.0	0.0	0.0
Construction	−2.6	0.0	0.0
Transportation	38.9	0.0	0.0
Post	0.5	20.0	0.9
Telecommunications	8.2	0.0	0.0
Commerce	−11.2	0.0	0.0
Restaurant	6.9	0.0	0.0
Finance	0.2	0.0	0.0
Insurance	−2.9	0.0	0.0
Real estate	0.0	0.0	0.0
Social services	38.8	0.0	0.0
Education and health	1.7	5.7	1.7
Public administration	−1.5	0.0	0.0
Total/average	409.5	11.2	2.5

Note: The imports of rice, wheat, corn, cotton, grain mill and vegetable oil are average of 1993–97. See Table A.1 for full names/description of industries.

Source: Chinese Social Accounting Matrix, 1997, Development Research Center of the State Council.

The third scenario looks at the impact of eliminating the Multi-Fiber Arrangement (MFA) quotas on textiles and clothing under the WTO Agreement on Textiles and Clothing (ATC). Textile-importing countries imposed the MFA quotas to protect domestic industries. The elimination of MFA removes an important barrier to Chinese exports.[4]

The fourth scenario incorporates a twenty percent productivity boost in automobile production. Contrary to initial expectations the automobile industry in China has held up well following WTO-accession. The story is detailed in Francois and Spinanger (2004), which is the source of the twenty percent estimate.

The fifth and final scenario includes all the effects of the previous scenarios.

While we quantify some aspects of WTO-accession in detail, we ignore other aspects. For instance, we ignore the reduction of barriers in service trade and foreign investment, protection of intellectual property rights, securing market access, enforcement of commitment and cooperation in dispute settlement. Therefore our analysis does not cover all aspects of the response to WTO-accession. In our view the most important aspects for shaping trade should be covered, however.

4. Model assumptions

The significance of our analysis depends on the model used and this section describes our environmental CGE-model. Model equations and more descriptions are provided in Appendix B. The main features of our model are listed in Table 3. The model belongs to a family of CGE-models used extensively over the past two decades to analyse the impact of trade policy reform (Dervis et al., 1982; de Melo, 1988). It is of the time recursive type with myopic savings. Investments adjust to savings. The time-recursive structure allows us to model the gradual phase-in of WTO. Below we describe the economic structure first and environmental aspects second.

5. Industry structure

There are 64 industries in the model, including 10 agricultural industries. The industries are specified in Table 1 above. Such

[4] Textile importing countries are allowed an option to reintroduce quotas if Chinese textile export grows more than 7.5% annually. In our scenarios exports grow less than that.

Table 2 – Summary of quantitative assumptions related to WTO accession

Scenario	Description		
S0	3% growth rate of import quota for goods subject to quantitative restrictions (Rice, wheat, corn, cotton, wool, vegetable oil, sugar, petroleum refining, automobiles) Exogenous export quota growth for textile and apparel Textile: 5.0% apparel: 6.2% (annual average) All tax rates are fixed at their base year levels Balance of payment gradually declines to 30% of its base year level in 2010.		
S1	Tariff reduction and quotas elimination on industrial products An average 55% cut in the 2000 tariff level between 2000–2008, based on the nominal tariff schedule in the China–US agreement Phased elimination of import quotas on petroleum refining and automobiles from 2000–2005 Initial quota in 2000-petroleum refining: 27.6 bn yuan automobiles: 496.8 bn yuan Annual growth rate of both quotas 15%		
S2	Agricultural trade liberalisation Introduction of tariff rate quota (TRQ) system		
		Initial quota in 2000 (billion RMB)	Annual growth rate of quota (%)
	Rice	8.57	18.8
	Wheat	11.58	7.2
	Corn	3.25	12.5
	Cotton	10.46	4.7
	Wool	6.35	4.5
	Vegetable oil	104.28	14.5
	Sugar	15.23	8.0
	Tariff cut of other agricultural goods, based on the nominal tariff schedule in China–US agreement		
S3	Phase out of MFA Acceleration of the MFA quota growth rate from 2000–2004 Quota eliminated in 2005		
S4	Productivity boost for automobile sector 20% productivity boost for the domestic automobile industry		
S5	The whole WTO accession package S1, S2, S3 and S4 combined		

a high number of industries allows us to model quota and tariff changes at an appropriate industry level, and in general makes for a broad representation of compositional changes across the economy. Fisher-Vanden et al. (2004) have recently shown the importance of modelling compositional changes in some detail, or else too much of the compositional response to policy is subsumed in residual productivity growth changes. The arguments for a high number of industries have to be balanced against arguments in the opposite direction (e.g., large number of technology parameters without empirical backing), which explains why we have not disaggregated even more.

Industries use the primary inputs capital, land, agricultural workers, production workers and professionals (nested CES-function). Land and agricultural workers are only used by agricultural industries. Production workers and professionals are only used by manufacturing and service industries. The model distinguishes between old and new capital. Substitution is easier for new capital (high elasticities of substitution). In addition to primary inputs, industries use intermediate inputs according to a 64-industry input–output matrix derived from regional SAMs for 1997.

6. Foreign trade

The model assumes there are two types of competitive firms – ordinary firms and export processing firms – that produce similar product varieties in the same industry. Ordinary firms sell to the domestic market or export to the rest of the world according to profit considerations, but there are costs of changing from domestic to export produce (CET-function). Export processing firms export only. The rest of the world considers products of export firms and ordinary firms to be almost equal (CES-function, high, but less than infinite substitution elasticities). We assume that China, being the 5th leading merchandise exporter in the world (WTO, 2003), has some ability to influence the world market price of its exports (high, but not infinite price-elasticities on export composites).

Consistent with the treatment of export, two types of imports are distinguished by the model. One is ordinary-trade import, which is subject to tariff and non-tariff barriers. Ordinary-trade import is further subdivided into consumption import and investment import. Beside ordinary import there is duty-free import. Most duty-free import is used as input for export processing firms, but some is transferred to the domestic market. Lately, Chinese import demand may have affected world market prices of oil and some materials. Whether that is a permanent phenomenon with enduring welfare impacts is not clear. Given China's small trade share in the world we assume for now that the world market price of imports is fixed in foreign currency. We comment on this assumption in the section on welfare impacts below.

We transfer the assumptions of each scenario to the model in the following way: Tariff reductions are exogenous. Quotas

Table 3 – Main features of the environmental CGE-model

Time recursive model with neoclassical closure
64 industries, of which 10 are agricultural, 32 are manufacturing and 12 are service
5 factors of production
Nested CES production system
Explicit treatment of processing trade
2 regions with urban and rural areas
ELES private consumption system
Imperfect mobility across regions and areas
7 pollutants to air
9 health damage end-points

on industrial goods and agricultural products are modelled in terms of their equivalent tariffs, and the quota premium ("pure rent") goes to domestic firms. The rates of industrial and agricultural quota rents are endogenous.

In the textile and apparel industries we treat the MFA quota on exports as an equivalent tariff added to the domestic export price. The tariff is endogenous. The quota premium goes to domestic firms.[5]

Our modelling of foreign trade allows us to capture important aspects of WTO-accession. In particular, accession lowers the tariffs and quotas facing ordinary imports and exports, and reduces the difference between ordinary firms and export processing firms. The reduction improves economic efficiency and has implications for regional disparity. The changes in efficiency and disparity in turn lay the conditions for the environmental response.

7. Regional aspects

The possible boost to trade from WTO accession has important regional implications. Accordingly we distinguish in the model between Guangdong Province and the Rest of China. Guangdong Province is home to 5% of China's population, but had nearly 40% of its trade in 1997 and more than 50% of its processing trade. Guangdong is also among the richest provinces in China. Its annual economic growth over the period 1978–97 was 14.2%, or 4.4 percentage points above the national average of 9.8%.

8. Households, consumption and government

Since the urban–rural divide is of great importance in China both generally and in studying the response to WTO we model one urban and one rural representative household per region (that is, four households in total). Households derive income from labor, land, firms, capital (directly) and transfers. Consumption and savings is modelled as an Extended Linear Expenditure System (ELES). The model also incorporates central and regional governments and two categories of public balances, as is the case in China: A government balance collecting taxes and an off-budget public balance collecting fees.

9. Frictions and distortions

The Chinese economy is characterized by significant frictions and distortions in geographical and labor dimensions. It is important to capture the distortions, as it is the interplay between the removal of WTO-related distortions and remaining frictions and distortions that forms the material welfare gain from WTO-accession. One set of frictions, which is already described, involves *export*. Ordinary firms coexist with export processing firms in most industries. Entry and exit into each category of firms respond to demand (recall that it is assumed that foreigners view similar products from ordinary firms and export processing firms as distinct varieties). Ordinary firms' export is further restrained by the cost of moving production from domestic to export purposes. This cost even applies to *inter-regional trade*. A second set of frictions relates to *migration and* labor *market segregation*. In China, barriers to migration include the household registration regime, discrimination in employment, education and social security etc. In particular it is difficult for a rural agricultural household to access the urban market for well-paid, skilled labor. On the other hand, it is often comparatively easy for a peasant to be accepted for unskilled industrial work in towns nearby (e.g., Hertel and Zhai, 2006). To model barriers migration we assume that labor flows freely between agricultural work and unskilled industrial work (production work) in the same province. We assume there is no migration between agricultural work/production work on the one hand and professionals (skilled work) on the other hand. In consequence the labor supply pool is much larger for unskilled work than for skilled work. This set of assumptions confirms with stylised facts of the "Chinese miracle".

Labor migration between provinces is induced by wage differentials. Assuming that members of the labor force differ in their opportunities and attitude with respect to provincial migration we assume that one percent wage differential induces 1.2 percent migration (CET-function). The elasticity of 1.2 percent is based on Borjas (2003) adapted by DRC to Chinese conditions.

In the capital market we assume that capital is invested in the province of the savers.

Since the interplay of WTO-accession and pre-existing distortions are important for results, and given the lack of exact evidence on barriers to trade and migration, we explore alternative assumptions in the section on sensitivity analysis.

10. Emission factors

We model emissions to air of the four air pollutants particulate matter (PM_{10}), SO_2, NO_x and VOC; and the greenhouse gases CO_2, CH_4 and N_2O. Emissions from an industry are determined by the industry's intermediate or final consumption of polluting inputs, mostly fossil fuels. In addition, industries may have emissions linked to output levels (e.g., fugitive emissions, as with natural gas leakage and volatile organic compounds). To our knowledge an emission inventory related to emission sources that runs over 64 industries does not exist in China. Like earlier studies (e.g., O'Connor et al., 2003; Aunan et al., 2007), we make use of emission coefficients associated with each type of consumption and production that were originally derived from the World Bank's IPPS project, using a methodology of Dessus et al. (1994). Total emissions are calibrated to be consistent with emission data in the EDGAR database (Olivier and Berdowski, 2001). For SO_2, NO_x and CO_2 the IPPS data thus provides relative coefficients, with EDGAR determining the level. For NMVOC, the data from IPPS appear incomplete and the apparently incomplete

[5] The division of pure rent between exporters and importers is discussed by de Melo and Winters (1993). De Melo and Winters argue that pure rent is shared between exporters and importers. If they are right our model overstates the income to Chinese households from quota rents and thus overstates the (partial) loss from eliminating the quotas.

industry estimates have been replaced with new coefficients. CH_4 and N_2O are originally not included in the IPPS dataset, while NMVOC, CH_4 and N_2O coefficients are constructed based on estimates in EDGAR and activity data available in the model that were known to drive emissions (input (e.g. coal or oil) or output). For NMVOC the replacements were made for crude oil and natural gas production, transport and residential biomass combustion. For CH_4 and N_2O the same approach was used. Each emission source in EDGAR is allocated to an IPPS sector and linked to fuel use (assuming fuel split from the International Energy Agency statistics) or output, depending on the characteristics of the source. Emissions from fertilizer and manure are distributed by crop-sector using data on N-input per crop from FAO (2002). Emissions from enteric fermentation and manure management are allocated to the sector livestock. Estimates of CH_4 from rice cultivation differ widely in the literature. EDGAR data are used to keep consistency with the other estimates. Estimates of total PM_{10} emissions for China are not available in the literature. SEPA publishes data on soot. Since for fossil fuel combustion black carbon normally constitutes a large share of PM emissions (Bond et al., 2004), we have used the soot data from SEPA as an estimate of total PM_{10}. The IPPS project again provided relative coefficients. Needless to say, there is uncertainty in the emission data we have constructed, but emission factors from key industries (e.g., power, cement etc) are reasonable.

Chinese emission factors (emissions relative to energy and output) have declined over time (e.g., World Bank, 2001). We assume a further exogenous reduction in emission factors over the simulation period, in accordance with recent projections from IIASA (Cofala et al., 2005). Without the reductions, model emissions would have grown at historically unprecedented rates, and the impact of WTO-accession on the environment and on public health would have been unrealistically high.

11. Health benefits

The model of health benefits flowing from emission reductions requires three steps. The three steps are explained in Aunan et al. (2007), and we briefly outline them here. In step one we use a stack-height differentiated dispersion model to estimate impacts on air pollution exposure from a given emission change. The air dispersion model was first elaborated in WHO (1989) and has recently used in a number of other studies (e.g., Garbaccio et al., 2000 for China, and Lvovsky et al., 2000 for six major cities in developing and transition economies).

In step two we use dose-response methodology to estimate impacts on mortality and morbidity health risk end-points. The health damage assessment is mainly based on Chinese epidemiological studies of dose response relationships between air pollutants and health effects and follows the approach of Aunan and Li (1999).

In step three we estimate unit values or prices of health risk end-points. A key estimate in this step is the value of a statistical life (VSL). Our VSL values are transferred from the Taiwanese hedonic wage study of Liu and Hammitt (1999). The VSL values are, for all China, $43,000, for Guangdong, $69,000, and for the rest of China, $42,000. The values are lower than the estimate in the authoritative survey of World Bank (1997), but higher than the low bound of a recent VSL-study from Beijing, China (Zhang, 2002). Her bounds are ($30,000; $200,000). In transferring the Taiwanese data to Chinese income levels of 1997 we assume an income elasticity of willingness to pay equal to one. On the other hand we do not adjust VSL upwards for future income growth in China. Therefore our VSL-value could be conservative. Assuming a higher VSL would have implied a greater impact of WTO-accession on the value of public health damage. We will se below that the practical relevance of this is low, however.

12. What to expect? Hypotheses on trade and environment

Previous literature (e.g., Grossman and Krueger, 1993; Copeland and Taylor, 2004) has identified at least three hypotheses regarding the impact of free trade on the environment. The *scale hypothesis* claims that production increases from free trade. The increase in production scales up pollution as well. The *composition hypothesis* says that free trade alters the composition of industries and affects pollution that way. If dirty industries expand, pollution increases and if clean (for instance, labor intensive) industries expand, pollution decreases. Often the case is made that the industries to expand will be dirty, a variety of the composition hypothesis known as the pollution haven hypothesis. Finally the *technique hypothesis* claims that production of a given good becomes cleaner following free trade. The idea is that free trade tightens environmental regulation and enforcement. That would either be a direct effect of trade, or an indirect one via higher incomes. As we will see below it may also turn up in macro as a side-effect of compositional changes. To be precise one should distinguish between trend improvement in technique and the impact of free trade on technique. The trend improvement in technique is important for some results and duly accounted for in this analysis, but only the impact of free trade on technique qualifies for the technique hypothesis.

A conceptually easy way to distinguish between the scale, composition and technique hypotheses is to imagine that emissions in the aggregate are described by the simple relationship

$$e = \alpha\beta x \tag{1}$$

Where e is emissions, α is emission intensity (measured, for instance, as aggregate emissions relative to aggregate fossil fuel consumption), β is the share of polluting industries in the economy (measured, for instance, as aggregate fossil fuel consumption relative to GDP) and x is GDP.

Using this relationship the percentage change in emissions is

$$\hat{e} = \hat{\alpha} + \hat{\beta} + \hat{x} \tag{2}$$

Where a hat over a symbol means elasticities/percentage change. If emissions decrease because $\hat{\alpha}$ is negative it would be evidence of the technique hypothesis. If emissions increase because $\hat{\beta}$ is positive it would be evidence of the 'pollution haven' realisation of the composition hypothesis, and if emissions decrease because $\hat{\beta}$ is negative it is evidence of the opposite realisation of the composition hypothesis. Finally if emissions increase because $\hat{x}$ is positive it is evidence of the scale hypothesis. To acknowledge the fact that there is truth in all hypotheses we will discuss the technique, composition and scale *effects*.

13. Economic drivers and impacts

The premise of this study is that the environmental impacts of WTO-accession are flowing from the economic changes. Therefore we initiate the discussion of environmental impacts by describing economic changes following WTO-accession.

GDP, the main macroeconomic indicator, is a precursor to the scale effect. We estimate that GDP increases 1.4% from accession. The reason for a positive impact is the familiar one that free trade improves economic efficiency. The reason it is modest is that the utilisation of labor and capital is determined by macroeconomic considerations outside the scope of the analysis. The utilisation rate ties up an aggregate like GDP. While common in CGE analyses, some readers might find the assumption of an exogenous utilisation rate questionable. One may object that in the short to medium term at least, the economy cannot significantly reallocate resources without repercussions on resource utilisation, which make for a negative scale effect. An objection to this view is that an economy like the Chinese is in dynamic movement and in any case undergoes large changes between now and ten years hence. WTO-accession is not about introducing change, but about influencing the direction of change. As such the degree of resource utilisation is unlikely to be affected by accession. If the argument about influencing the direction of change is valid and WTO does not affect total factor productivity (another matter of discussion) then it follows that the impact on GDP is positive but modest.

The output change at the industry level is a precursor for the composition effect. Fig. 1 shows that WTO-accession brings about significant industrial reallocation. A table corresponding to Fig. 1 is given in Appendix A. Refined petroleum and automobile production, two industries that were protected by import quotas previous to WTO-accession, lose their protection and decline 10–15% relative to the baseline. In the case of automobile production the decline occurs despite the twenty percent productivity increase. Other industries that lose terrain are vegetable oil, wool, sugar and rice. These agricultural goods were subject to import quota protection pre WTO-accession. The removal of that protection exposes problems of costs and productivity, and output declines between 8.5% (rice) and 20% (vegetable oil). At the other end, textile, apparel and industries supplying inputs to textile and apparel like cotton and chemical fibres, that is the textile cluster, gain impressively from accession. Textile and apparel each gain almost 50% relative to the baseline. The increase in production of textile and apparel is motivated by the lifting of export quotas. Lifting export quotas removes restrictions to export and the industries are allowed to make full use of their competitive strength. The associated increase in cotton production occurs despite the fact that cotton was protected by import quotas previous to accession. Removing the import quotas obviously hurts cotton, but on the other hand, demand from textile and apparel increases more than enough to compensate for that.

Among the industries experiencing smaller changes, electricity production, which is coal-based in China, is particularly interesting from an environmental point of view. Since GDP increases, one expects an increase in electricity production from the scale effect. Instead, electricity production declines 1.2%. In fact we obtain almost a three percent increase in the productivity of electricity, indicating a substantially cleaner economy from that perspective. It is the side-effect of 'primary' industrial reallocations that leads to higher electricity productivity: electricity demand from expanding industries is on balance lower than demand from contracting industries.

Other heavy pollution industries, such as iron and steel, chemical products and building materials including cement also face reduced demand as side-effect of primary industrial reallocation. The reductions range from half a percent for building materials to more than 4% for iron and steel. The decline across the board in heavy industry production

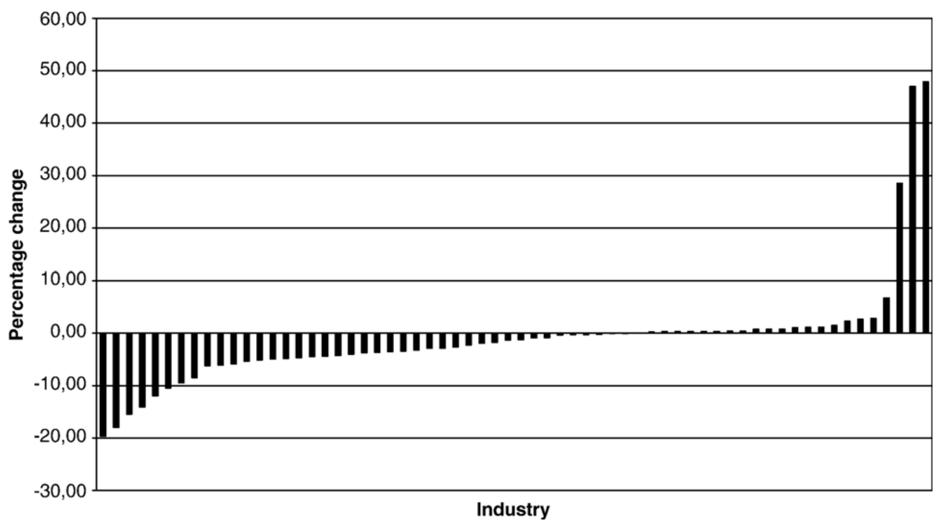

Fig. 1 – Industrial reallocation following WTO-accession. Impacts on output 2010 (corresponding to table in Appendix A).

Table 4 – Emission change (%) and its sources in terms of a macro production function

	Emission change	Contribution from technique effect	Contribution from composition effect	Contribution from scale effect
PM_{10}	−1.26	−0.51	−2.12	1.39
SO_2	−1.07	−0.31	−2.12	1.39
NO_x	1.45	2.23	−2.12	1.39
VOCs	0.14	0.90	−2.12	1.39
CO_2	−0.76	0.001 [a]	−2.12	1.39
CH_4	−3.24	−2.51	−2.12	1.39
N_2O	−0.61	0.12	−2.12	1.39

Note: CH_4 and N_2O emissions are largely determined by non-energy sources, therefore the decomposition has limited value. Eq. (2) does not quite hold for discrete changes, thus the numbers do not add up in the second digit.
[a] By assumption.

reinforces the message that important pollution drivers are weaker after accession than before.

14. Environmental impacts

Comparing the accession scenario with the baseline we wish to describe our results in terms of the scale, composition and technique effects. We compute the percentage change in emissions relative to the change in fossil energy and interpret the resulting numbers – one for each pollutant – as the contribution of the technique effect. We compute the percentage change in fossil energy relative to the change in GDP and interpret the resulting number as the contribution of the composition effect. Finally we computed GDP growth above, which gives the contribution of the scale effect. In line with the theoretical framework we assume a production function approach and unlike some other authors do not isolate household emissions. Household emissions are small compared to overall emissions in China.[6]

The model does not calculate fossil fuels in physical energy units, which complicates the calculation of the composition effect. We use CO_2-emissions as a proxy for energy in physical units, since energy related CO_2 emissions are proportional to fossil fuel consumption. The approach ignores fuel switch, e.g., from coal to gas, but fuel switch is low between scenarios in the coal-based Chinese economy. Since we do not allow for fuel switch we overstate the composition effect somewhat. The results are shown in Table 4.

The analysis predicts moderate effects of WTO-accession (the left-hand column), a prediction consistent with the message that usually comes from CGE-models and is reasonable to relate to the moderate change in GDP (scale effect). Accession reduces emissions of CO_2, CH_4 and N_2O, that is all the greenhouse gases.[7] It also reduces health-threatening particulate (PM_{10}) and SO_2 emissions. On the other hand, emissions of NO_x increase. Increases in NO_x-emissions may contribute to increased ozone-formation, which therefore could be a problem accentuated by accession. However, the overall environmental message from the simulations is, in our view, fairly positive.

A positive number in any of the three right-hand columns indicates a contribution to higher emissions. A negative number indicates a contribution to lower emissions. Thus the scale effect contributes to higher emissions; the composition effect contributes to lower emissions and the technique effect contributes to lower and higher emissions depending on pollutant.

With the exception of NO_x Table 4 points to the composition effect as the main driver of emission changes. The aggregate fossil fuel intensity, indicating compositional changes in the economy, falls 2.1% and outweighs the 1.4 percent scale impact of higher GDP. The reason the fossil fuel intensity falls is primarily that production is lower in the heavy pollution industries headed by power. Lower production in heavy industries is part of the response to the first-order industrial reallocation in response to tariff and quota reductions. Chief among the first-order reallocations is the lifting of the Multi-fiber agreement, which pulls resources in the direction of the textile cluster. Some of those resources are pulled from previous foreign exchange earners. The textile and apparel cluster consumes less energy per unit of output than the previous foreign exchange earners, in particular iron-and-steel, chemical and building materials. Electricity demand goes down and the result follows.[8]

To see how the composition effect translates into lower emissions, consider SO_2. Before accession power, iron and steel, chemicals and building materials emit 66% of China's SO_2 emissions. After accession energy demand of these industries declines roughly in parallel to declines in output. As a result the share of SO_2 emissions belonging to the four industries goes down, but they continue to emit 65% of emissions. Why is the share not lower? One reason is that gross SO_2 emissions decline by roughly 1%, see the left column of Table 4. Thus the share of any one industry will only go down if the industry experiences a larger decline than 1%. In fact, for the share to decrease from 66 to 65% the emission decline in the four industries is 2.5%.

The 2.5 percent decline is made up for, and the minus one percent aggregate is reached via increased emissions from expanding industries. In the case of SO_2 emissions from textiles and apparel increase more than 40%, while emissions from production of chemical fibres increase almost 30%. Interestingly SO_2 emissions from transport increase only half a percent despite a lower price of cars. More industry results are shown in Appendix A.

[6] In the base-year, household emissions are between 1–6% of total emissions of the classical pollutants.

[7] Remember that the reduction is relative to the baseline level in 2010, which is higher than any time before. It is as correct to say that accession reduces the growth rates of greenhouse gases.

[8] This study does not consider emission changes outside China's borders. However, it has been claimed that as its import demand for resources grows, China's growth increasingly relies on ecological services appropriated from abroad. In other words, a reasonable hypothesis is that the domestic composition effect is modified by a foreign composition effect. It will generally not be neutralised, however, since net demand for various products and goods changes after accession. That is, (domestic production + imports) changes.

Table 5 – Emission changes (%) per scenario

	WTO accession package (S5)	Removal of tariffs and quotas on industrial products (S1)	Agricultural trade liberalisation (S2)	MFA elimination (S3)	Automobile productivity boost (S4)
PM_{10}	−1.26	−0.48	0.92	−1.50	0.18
SO_2	−1.07	−0.81	1.00	−1.09	0.16
NO_x	1.45	0.20	0.75	0.06	0.20
VOCs	0.14	0.83	0.76	−1.45	0.21
CO_2	−0.76	−0.19	0.79	−1.26	0.17
CH_4	−3.24	−0.60	−0.34	−1.88	0.09
N_2O	−0.61	0.30	−1.70	0.71	0.06

Note: percentage change relative to the baseline scenario, 2010. Scenarios 1–4 do not sum to scenario 5 because scenarios 1–4 show the effect of one policy aspect at a time and do not accumulate them.

As mentioned, most theoretical expositions relate the technique effect to tighter environmental regulation post WTO-accession. By contrast, the technique effect of Table 4 is a consequence of industrial reallocation and is therefore driven by the same forces as the composition effect. Different industries have different emission factors per unit energy consumption, depending on differences in techniques as well as differences in abatement efficiency. In the case of SO_2 the content of S in coal also could differ between industries.

We do not emphasise small changes in the technique effect. The IPPS dataset used for industrial emissions captures generic properties of emission factors, but it does not capture properties that are specific to the context of China.

15. Environmental impacts per scenario

To learn more about the environmental impacts and how they are linked to the technique, composition and scale effects, we study the scenarios that simulate the elements of the accession package one by one. Results are collected in Table 5.

Scenario 1 on removal of tariffs and quotas on industrial products obtains qualitatively similar results to the full accession package. Recall that the elements of scenario 1 are removal of import quotas on automobiles and refined petroleum, as well as removal of import tariffs on industrial products. As a result, industries competing with imports lose market shares and the balance of trade deteriorates. To restore equilibrium and defend the balance of trade, domestic costs fall, with an across the board expansion of net exports as the consequence. The contraction of industries competing with import, coupled with an expansion of export industries leads to industrial reallocation. The industrial reallocation implies lower emissions of PM_{10}, SO_2 and CO_2, but higher emissions of NO_x and VOC. Since resources to defend the balance of trade are drawn from agriculture as well, CH_4 and N_2O emissions also are lower.

Scenario 2 on agricultural trade liberalisation brings out the effect of reallocating resources from agriculture to manufacturing industry. In this scenario agricultural imports increase at the expense of domestic production. Production of wool, for instance, is predicted to decline 40% (but recoups half to the loss through other elements of accession). Cotton production declines 10%, and rice 7.5%. The negative impact on agricultural sectors explains why emissions of the agricultural pollutants CH_4 and N_2O decline with agricultural trade liberalisation. The decrease in CH_4 is for instance fully explained by the fall in rice production. Despite barriers to migration from agriculture to manufacturing industry, resources are reallocated to manufacturing in order to defend the balance of trade. As a result, all industry related emissions increase.

Scenario 3 on the multifiber export quotas captures the effect of a reallocation to the textile cluster. Since the effect of eliminating the quotas shines through in the total accession package, it is not surprising that the effects of this scenario are qualitatively the same as for the total package. However, the environmental impacts are quantitatively better than in the full package. The reason is that we get higher reallocation in the direction of the textile cluster than in the full package. In fact the elimination of the multifiber quotas is the main driver behind the reductions in emissions that we gain with the full package.

Scenario 4 on the automobile productivity boost offers the somewhat surprising prediction that emissions of all substances increase. The culprits are the scale and composition effects.[9] The composition effect in this case captures the impact of the automobile industry producing more than it would otherwise have done, since a productivity increase in the industry leads to lower prices in a competitive environment, and higher production. The scale effect captures the effect of the automobile productivity boost yielding higher incomes (both at original production levels, and even more so after optimal reallocation) which spread out in the economy in the form of higher demand, supply and emissions. The empirically interesting feature of the automobile productivity boost scenario is that the composition and scale effects more than outweigh the technique effect. A boost to the productivity of the automobile sector is negative for the environment.

16. Impacts on public health and welfare

This section puts environmental impacts in perspective by describing impacts of WTO-accession on public health, consumer's surplus and distributional impacts. These are ingredients of a welfare analysis.

[9] Composition and scale effects that originate with a productivity increase (an original technique effect) are known collectively in the environmental engineering literature as "rebound effects".

17. Impacts on public health

Table 6 reports our estimates of monetary public health improvements. We obtain improvements in health status since emissions of PM_{10} and SO_2 are lower after WTO-accession. PM_{10} and SO_2 are the main precursors of health damage. The improvements in health status vary between end-points, with fewer work days lost and fewer asthma attacks causing the highest percentage improvement. The percentage change in total health benefit is smaller in size than the change in emissions of either PM_{10} or SO_2. That reflects non-linearities and thresholds in the dispersion and dose–response relations.

Our monetary estimate of impacts on public health includes nine end-points, but there are additional benefits and costs we do not include. The benefits of lower greenhouse gas emissions are not explicitly assessed. On the cost side we reiterate that WTO-accession seems to imply increased ozone formation through increases in emissions of the precursors NO_x and NMVOC. Ozone has adverse health impacts that we do not include.[10]

18. Impacts on aggregate welfare

In economic terms the tariffs and quotas on imports and exports are distortions that reduce the efficiency of the economy. Allowing for the fact that trade distortions interact with other distortions described above like barriers to labor migration, it is the removal of distortions that is the source of most of the material welfare gain from WTO-accession. Higher productivity in the automobile industry gives an additional gain.

Despite the removal of distortions and significant reallocation of resources in its wake, the overall gain in static 2010 material consumer's surplus (equivalent variation) remains modest at 1.14%.[11] The gain increases to 1.16 when we add in the money equivalent benefits to public health. The small impact of public health relates to our assessment of the cost to public health in the baseline. It is modest at 2.3% of GDP. Since it only changes 0.6% it goes without saying that the impact on consumer's surplus lies in the second digit. From these estimates we note that the VSL-estimate is insignificant for results.

19. Impacts on distribution

WTO accession benefits urban households more than rural households, see Table 7.

The difference is not very large, however, for China as a whole. The interesting effect occurs in Guangdong, which is the home of much of the textile cluster. Urban households in Guangdong gain four times more than the average citizen. The reason urban households in Guangdong gain more is that many of them work as skilled professionals, and the demand for professionals increases as the textile cluster and other industries in the province experience higher demand. Wages of professionals are bid up and urban households gain. By contrast, wages of unskilled production workers are held down by the fact that production workers are drawn from a large pool of rural laborers. In short, the labor market increases dispersion between skilled urban households and unskilled rural households. The estimated improvement in public health also benefits urban households disproportionally, since reductions in PM_{10} and SO_2 mainly take place in urban areas.

Not all aspects of accession work against unskilled rural households. Removing quotas and tariffs on industrial goods benefits rural households since it drives down prices on goods they consume. Urban households both consume and produce these goods, and lose in their capacity as producers. Lower prices on industrial goods is the most important effect outside Guangdong and allows rural households to hold their relative position vis à vis the urban households there.

20. Sensitivity analysis

In Section 4 above we claimed that the interplay between WTO-accession and preexisting frictions is driving the efficiency gain and also the environmental response to accession. The interplay between removing one distortion and keeping others is the core of the second best effect that is of interest to economists when studying public finance problems. The CGE model is well suited for analysing second best effects, which generally cannot be determined on theoretical grounds.

In this section we present experiments in which we vary the extent of pre-existing distortions and analyse the impacts on GDP and SO_2-emissions respectively. We choose SO_2 as our

Table 6 – Monetary benefits to public health from WTO accession

Mortality, cases	0.39
Outpatient visits, cases	1.01
Emergency room visits, cases	0.47
Hospital admissions for respiratory reasons, cases	0.76
Work day losses, days	1.34
Respiratory symptoms in children, cases	1.20
Respiratory symptoms in adults, cases	1.09
Chronic respiratory symptoms in adults, cases	1.01
Asthma attacks, cases	1.34
Weighted sum	0.65

(%) relative to baseline environmental damage to health.

Note: Positive number means benefits, i.e., the value of fewer cases/units.

[10] However, we have investigated the impact of increased ozone formation on agricultural yields, using a methodology described in O'Connor et al. (2003). The impact on productivity is below 0.1 percent since NO_x and VOC emissions change fairly little.

[11] One reason the gain is lower than the gain in GDP is terms-of-trade effects. By that we mean that the more China exports, the lower are the prices of exports. See, e.g., Vennemo (1990) for more on the terms-of-trade effect in CGE welfare analysis. The assumption that Chinese households get all of the quota rent is also important for the gain. Had we modelled a split of quota rent with foreigners, elimination of quotas would have a implied a transfer from foreigners to Chinese that would have increased the Chinese aggregate welfare gain. Using production-weighted import tariffs would probably also have increased the gain. On the other hand, assuming import prices to increase in imports would have decreased the gain.

Table 7 – Equivalent variation

		Whole WTO accession package (S5)
China	Urban households	1.17
	Rural households	1.08
"Rest of China"	Urban households	0.81
	Rural households	1.01
Guangdong	Urban households	4.49
	Rural households	1.76

Percentage change relative to the baseline scenario.

indicator of emission changes since it perhaps is the air pollutant of greatest concern in the Chinese policy debate. Effects on other pollutants are not significantly different from effects on SO_2.

Results of sensitivity analyses are collected in Fig. 2. All impacts are relative to the base case impact, i.e. the increase in GDP of 1.4% and decrease in SO2 of 1.1% that we have discussed before. The words increase and decrease now refer to changes relative to the base case impact. We discuss the scenarios from the bottom up.

Scenarios T-1 and T-2 consider frictions with respect to trade. In scenario T-1 we reduce by one half the elasticities of transformation between domestic and export production, and between local production and regional trade. Scenario T-2 builds on scenario T-1 and reduces by one half the elasticities of substitution between domestic production and imports. These changes make it more cumbersome for the Chinese economy to profit from the possibilities of WTO-access, and GDP decreases. At the same time SO_2-emissions increase (in T-1). We conclude that China loses both economically and environmentally the worse the country is at transferring resources from domestic production to trading sectors. By contrast a smooth transfer of resources facilitates benefits, not just economically but even environmentally as far as SO_2 is concerned.

Scenarios F-1 and F-2 study the impacts of parametrically imposing barriers to peasants wishing to enter into unskilled production work. Recall that in the base case unskilled production workers and peasants are drawn from the same labor pool. In scenario F-2 the two are completely separated. Scenario F-1 is an intermediate case in which a one percent increase in the relative wage of production workers leads to 1% more production workers, and vice versa.

The barriers introduced in scenario F-1 and F-2 reduce the size of the GDP gain, and reduce SO_2-emissions disproportionally. The reason GDP is reduced is that expanding industries no longer find it as easy to hire new production workers. Expanding industries must bid up the wage, and, in the case of scenario F-2, they must make do with the pre-existing stock of production workers. Obviously that makes it difficult to make use of the opportunities provided by WTO-accession. The result is that more labor stays in agriculture and industries are developed less. Although negative in terms of economic efficiency that development has beneficial scale and composition effects on SO_2-emissions. Agriculture is of course a small source of SO_2 emissions compared with industry and power.

Scenario F-3 to F-7 do not significantly change the base case impacts. In particular the impacts on SO_2 are insignificant. In scenario F-3 workers migrate effortlessly between provinces. All production workers and peasants belong to one labor pool, and all skilled workers belong to another pool. The impacts are insignificant. In scenario F-4 labor migration between provinces is disallowed. Again the impacts are insignificant. Obviously migration between production work and agriculture (F-1, F-2) is more important than migration

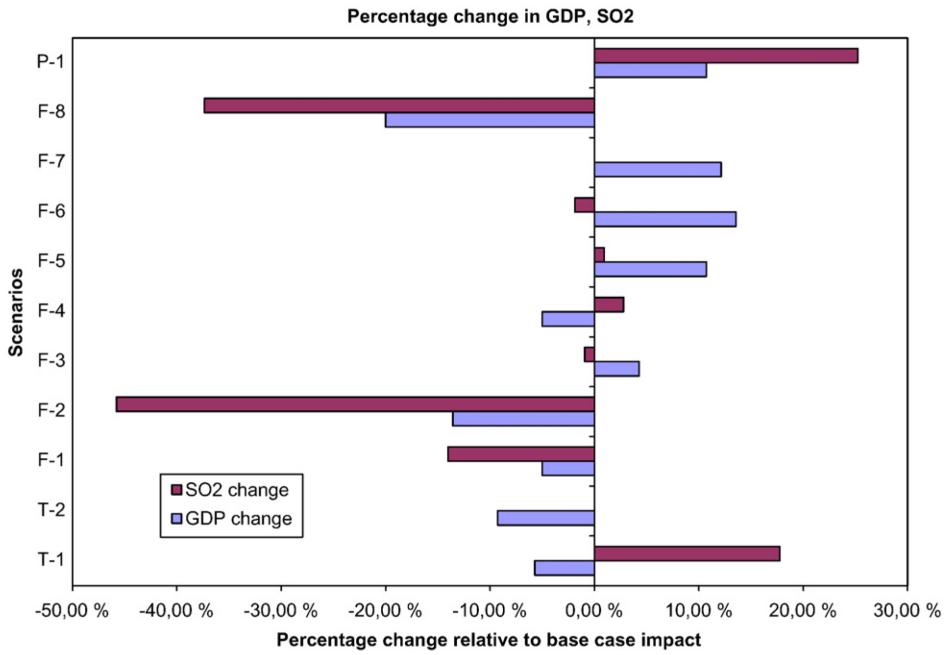

Fig. 2 – Percentage change in GDP, SO_2.

between provinces. In scenario F-5 and F-6 we explore the impact of allowing capital mobility between provinces. In F-6 there is one national capital market. In F-5 a one percent rate of return differential induces one percent capital mobility. Once again the impacts are insignificant, particularly for emissions. Scenario F-7 combines F-3 and F-6, that is, two national labor markets (skilled professionals versus unskilled production workers and peasants) and one capital market. Again we find insignificant results for emissions in particular.

Scenario F-8 combines the assumption of zero mobility between agriculture and production work (=F-2) with an assumption of zero mobility between provinces (=F-4). This is the case of completely segregated labor markets both geographically and between skill types. The impact on GDP and emissions is significant and comparable to the impact of scenario F-2. Results are obviously vulnerable to the mobility between these kinds of labor.

In scenario P-1 we reduce all substitution elasticities in production functions by one half. The consequence is that GDP increases, and SO_2-emissions increase from a scale effect. The effect on GDP is as expected. With an inflexible production structure the gain from removing tariffs (of a given size) is high, just as the cost of accommodating a distortion/tariff wedge is high.

21. Discussion and conclusions

We have found that WTO accession improves China's environment as far as main air pollutants are concerned. There are also gains to public health and aggregate welfare, but the distribution becomes more skewed. The reason for these developments is that WTO induces a new course for industry growth. The textile and apparel industries, already China's largest export earners, gain tremendous momentum and increase close to 50% after WTO-accession. The growth of these and industries supplying their inputs draw resources from heavy industry and from agriculture. In short we find a "composition effect" that is favourable to the environment.

The emphasis on a favourable composition effect is somewhat at odds with most of the literature on trade and environment. That literature, which recently is reviewed in Copeland and Taylor (2004), generally finds that the composition effect from free trade is weak but probably negative for the environment. The reason it is negative is that developing countries often have a comparative advantage in pollution intensive goods that liberalised trade allows them to utilise better. The reason it is weak is that developing countries at the same time have a comparative advantage in labor-intensive goods, which tend to be less polluting.

The reason we find a positive composition effect in our material is that the comparative advantage in the labor dimension dominates. A main effect of WTO is to lift export restrictions in the textile and apparel sectors. These are labor intensive, but not pollution intensive as far as air is concerned. In our material we recognise the comparative advantage in labor, but not the comparative advantage in pollution.

Why is it that WTO-accession does not allow China to play out its comparative advantage in pollution intensive goods? It is useful to distinguish between different elements of accession. Perhaps paradoxically, agricultural import barriers do seem to have a link with China's pollution advantage. Removing agricultural import barriers encourages industrial production, building on comparative advantage of the traditional sort (labor and pollution advantage). From Table 5 above we see that pollution goes up from that aspect of accession in isolation. Removing industrial import barriers on the other hand, actually leads to a decline in pollution intensive goods since pollution intensive industry loses when the protection is lifted. On the export side the quota under the Multi-Fibre Agreement is a significant barrier to Chinese labor advantage, but except for NO_x and VOC, it is not a barrier to an air related pollution advantage. It is the textile cluster that gains from removing the export barrier, and the cluster is not a major source of air pollution in China.

In conclusion it is mainly removal of agricultural import barriers that exposes traditional pollution intensive comparative advantage, but the agricultural barrier is not dominant in the accession package. Thus, the composition effect of free trade is positive for the environment.

It should be added that the textile and apparel industries contribute much more to water pollution than air pollution. Data from NBS (2006) indicate that textile is the third largest source of wastewater discharge behind pulp and paper, and chemicals. Given the fifty percent increase in economic output, a similar increase in water pollution from textile and apparel industries should be expected. In Guangdong the increase would be more than 100%. If the competitiveness of the textile and apparel industries is due not only to low labor costs, but also to lax water pollution regulatory costs, the composition effect in the direction of the textile cluster is in part due to the pollution advantage of the textile and apparel industries.

It is worthwhile to compare our results to those of He (2005), who in one scenario considers the impact of WTO-accession on GDP and on SO_2. He (2005) runs his CGE model 1997–2005, and finds an increase in GDP from accession of 0.75% in 2005, while SO_2-emissions increase 1.6%. The impact on GDP is comparable to ours, but He gets a different sign on his SO_2-impact. A main reason seems to be that he obtains an increase in electricity production, while we find a decrease. Some of the potential reasons why he gets a different impact on electricity production can be eliminated. Both models rely on a SAM of 1997. Both have a large number of industries (55 versus 64 in this study) and a similar number of energy industries (four versus six here). Both use nested CES-functions in production. However, the details of the trade experiment are different. In particular He does not include quota elimination and is not explicit about the difference between nominal and effective tariff rates. His results with respect to industrial reallocations are smaller than ours. Differences in the modelling of the trade experiment may be one reason why he obtains a different sign on the SO_2-impact.

We also briefly compare our results with studies contained in CCICED (2004). The study of the energy sector in that report (Jiang et al., 2004) finds higher emissions to air, particularly from electricity production, but that is because the study *assumes* that production of energy intensive industries will increase following accession. Our model based analysis of course concludes otherwise, production of energy intensive industries falls. The study of the textile industry in CCICED (Cheng et al., 2004) estimates a two-equation forecast model to find that the industry will gain almost 50% from accession, which is similar to our finding. The study of agriculture (Hu,

2004) finds that agricultural production falls, again similar to our finding. Lower agricultural production brings lower water and pesticide consumption, and lower discharges to water.

In a complex model of economy-wide impacts there are many points to improve on. Thus the analysis we have presented may be improved in several ways. One direction of improvement would be a better representation of WTO-accession, in particular the liberalisation of services and the issue of intellectual property rights; and the aftermath of WTO accession in the form of (more or less endogenous) policy responses. That would allow a richer discussion of the technique effect. Another direction of improvement concerns the model of the economy that WTO-rules feed into, e.g. the emission factors employed. A China-specific emission factor data set is highly desired. A third direction of improvement relates to technology and heterogeneous industries. It is for instance not unlikely that new plants established e.g., by the composition effect are cleaner and more efficient than the average in the industry. Still, despite shortcomings we believe that our analysis has brought to the table new evidence on the environmental implications of Chinese WTO accession in particular and environmental implications of freer trade in general.

Appendix A

Table A1 – Industrial reallocation following WTO-accession. Value added and SO_2 emissions. Percentage change impacts 2010

Industry	Value added	SO_2 emissions
Vegetable oils	−19.68	−17.93
Wool	−18.00	−18.99
Motor vehicles	−15.42	−14.74
Sugar refining	−14.05	−14.07
Measuring and office equipment	−11.96	−9.67
Petroleum refining, coking	−10.46	−10.32
Electronic and communication equipment	−9.46	−8.28
Rice	−8.50	−14.31
Other manufacturing goods, scrap and waste	−6.21	−1.97
Crude petroleum production	−6.07	−5.76
Forestry	−5.83	−3.42
Ferrous ore mining	−5.29	−3.98
Toys, recreation goods, culture and arts	−5.08	−3.65
Non-ferrous ore mining	−4.90	−4.64
Non-ferrous metal smelting and processing	−4.82	−3.82
Electric appliances, equipment and machinery	−4.68	−2.76
Iron-, steel-, alloy iron smelting and processing	−4.46	−4.53
Industrial machinery, boilers, engines, turbines	−4.41	−4.14
Logging and transport of timber and bamboo	−4.25	−3.96
Leather and fur	−3.98	−5.80
Paper and paper products	−3.72	−4.59
Natural gas production	−3.66	−2.95
Rubber products	−3.51	−3.42
Corn	−3.41	−0.62
Metal products	−3.20	−2.39
Machinery for agriculture, forestry, fishery and manufacturing industry.	−2.87	−2.88
Coal mining	−2.85	−1.76
Plastic products	−2.62	−2.27
Sawmills and fiberboard	−2.24	−2.24
Wheat	−1.92	0.81
Chemical materials, fertilizer, pesticides	−1.75	−2.00
Transport equipment, railroads, ship building, aircraft, bicycle	−1.27	−2.69
Electricity and heat/steam production and supply	−1.21	−3.26
Furniture and other wooden products	−0.88	−0.88
Non-metal minerals-, salt- and other mining	−0.83	0.17
Building materials — fire-proof: cement, bricks, tiles, glass, earthenware	−0.37	−0.73
Medical and pharmaceutical products	−0.29	−0.24
Telecommunications	−0.23	9.68
Other crops	−0.22	4.86
Public administration	−0.02	0.36
Tobacco	−0.01	−0.07
Health and education, sport, media, research and technical services for primary industries	0.09	−0.13
Gas production and supply	0.22	–
Other agricultural output	0.33	−0.13
Alcoholic and non-alcoholic beverages	0.34	0.01
Post	0.34	4.78
Printing, audio and video reproduction	0.36	0.35
Insurance	0.36	0.10
Tourism and recreational service	0.43	−1.08
Food processing: meat, fish, eggs, dairy etc	0.43	−0.08
Transport, freight and passenger	0.77	0.50
Construction	0.78	2.66
Fishery	0.80	0.80
Restaurants and bars	1.07	1.38
Grain mill products and forage	1.13	1.41
Finance	1.18	0.83
Water production and supply	1.48	1.17
Real estate	2.32	0.63
Wholesale and retail trade	2.69	9.28
Livestock (excl wool)	2.84	1.84
Cotton	6.74	11.70
Chemical fibres	28.57	26.18
Textiles: Cotton, woolen, hemp, silk; knitting mills, other textiles	47.02	42.99
Wearing apparel	47.91	41.35

Note: Column value added corresponds to Fig. 1 in text.

Appendix B. The two region environmental CGE Model for China (DRC-CGE)[12]

B.1. *Set definitions and symbol conventions*

Table 1 – Indices used in the model

i,j	Sector indices. The model includes 58 non-energy commodities and 6 energy commodities.
l	Labor types, namely, agl for agricultural labor, usk for production workers and skl for professionals.
h	Households types, uh for urban households, rh for rural households
f	Final demand expenditure categories, namely, *g* for government consumption, inv for investment, st for changes in stocks.
g	Government sectors, lg for local government, cg for central government, nfp for off-budget
c	Firm types, namely, *o* for the ordinary enterprises and *p* for the processing export enterprises.
m	Import types, namely, *o* for ordinary imports, *z* for the import of investment goods for foreign owned enterprises and export processing enterprises, and *p* for the import of processing trade.
r	Regions, GD for Guangdong province, ROC for the rest of China
stck	Height of emission sources, high, low and medium
p	Pollutant types
d	Disease types
T	Time index

Notes: Uppercase Roman letters indicate variables. Greek letters or lowercase Roman letters refer to parameters. Subscripts denote the set indexes. When a subscript refers to a subset or an element of sets, it is separated from other subscripts by comma.

B.2. *General mathematical features*

Production and demands in the model are characterized by multilevel nesting. The building blocks of the model are *composite goods* (factors) and the corresponding *component* conditional demand functions. Component refers to component of the composite good/factor. The composite good price is a unit cost of function that is dual to an aggregator function (Diewert, 1982). The aggregator function is assumed to be positive, twice differentiable linear homogenous, and quasiconcave. In our model, it has the CES form

$$Q = A \times \left(\sum_{i=1}^{n} a_i \times x_i^{(\sigma-1)/\sigma} \right)^{\sigma/(\sigma-1)} \qquad (A.1.)$$

where Q is the composite, *A* is the productivity parameter, x_i is the ith component in the aggregator function, a_i is the share parameter associated with x_i , i=1, 2, …, *n*, and σ is the elasticity of substitution. When Q=1, the unit cost function that is dual to it has the form

$$C(P,1) \equiv c(P) = \frac{1}{A} \left(\sum_{i=1}^{n} a_i^{\sigma} \times p_i^{(1-\sigma)} \right)^{1/(1-\sigma)} \qquad (A.2.)$$

where *C*(*P*,*Q*) is the cost function, *c*(*P*) is the unit cost function, *P* is the *n*-dimensional component price vector, and p_i is the price of component *i*. By applying Shephard's lemma to the cost function *C*(*P*,*Q*), the conditional demand function of component *i* in Eq. (A.1) can be derived as

$$x_i(P,Q) = A^{\sigma-1} \times \left(a_i \times \frac{c(P)}{p_i} \right)^{\sigma} \times Q \qquad (A.3.)$$

i.e., it is a function of the share parameter and the ratio of the composite price (unit cost) to the corresponding component price, multiplied by the total aggregate quantity.

B.3. *Production*

The model includes two regions, namely Guangdong (GD) and Rest of China (ROC). Each region has the same production structure.

The model assumes that there are two types of competitive firms – *ordinary firms* and *export processing firms* – that produce the same product in the same industry. Four level nested CES production functions are utilised to characterize the production structure of the two types of firms in each sector. In addition each sector distinguishes in production between old and new capital. In each nest, there is a composite price or unit cost function and its corresponding component demand functions similar to Eqs. (A.2) and (A.3). The only differences in specification between nests are variable names and the parameter values.

B.3.1. *Top level*

Sectoral output $XP_{j,c,r}$ is produced by the two inputs $ND_{j,c,r}$, the non-energy intermediate input, and $KEL_{j,c,r}$, the primary factors plus the energy bundle. The price for $XP_{j,c,r}$, $PX_{j,c,r}$ is the unit cost, while the demands for the two inputs $ND_{j,c,r}$ and $KEL_{j,c,r}$ are specified as component demand functions.

$$ND_{j,c,r} = \alpha^{nd}_{j,c,r} \left(\frac{PX_{j,c,r}}{PND_{j,c,r}} \right)^{\sigma^p_{j,c,r}} XP_{j,c,r} \qquad (P-1)$$

$$KEL_{j,c,r} = \alpha^{kel}_{j,c,r} \left(\frac{PX_{j,c,r}}{PKEL_{j,c,r}} \right)^{\sigma^p_{j,c,r}} XP_{j,c,r} \qquad (P-2)$$

$$PX_{j,c,r} = \left[\alpha^{nd}_{j,c,r} PND_{j,c,r}^{1-\sigma^p_{j,c,r}} + \alpha^{kel}_{j,c,r} PKEL_{j,c,r}^{1-\sigma^p_{j,c,r}} \right]^{1/(1-\sigma^p_{j,c,r})} \qquad (P-3)$$

B.3.2. *Second level*

The intermediate input, $ND_{j,c,r}$, is split into each non-energy commodity, $XAP_{n,j,c,r}$, according to a Leontief technology. Its price, $PND_{j,c,r}$, equals an I/O coefficient-weighted-average price of each non-energy commodity input.

$KEL_{j,c,r}$ is aggregated over total labor, $AL_{j,c,r}$, and the capital, land and energy input bundle, $KE_{j,c,r}$. Its price, $PKEL_{j,c,r}$, is the unit cost, while demands for $AL_{j,c,r}$ and $KE_{j,c,r}$ are specified as component demand functions.

B.3.3. *Third level*

$AL_{j,c,r}$ is aggregated over three skill levels of the labor force. The sectoral average wage, $AW_{j,c,r}$, is the unit cost function. Labor

[12] This appendix is based on an unpublished description of the single-region CGE model DRC-CGE, written by Fan Zhai.

demand by skill, $LD_{l,j,c,r}$ is specified as component demand functions. $AW_{j,c,r}$ is a CES aggregate of sectoral wages $wagedist_{l,i,r}W_{l,r}$.

$$AW_{j,c,r} = \left[\sum \alpha^{ls}_{l,j,c,r}(W_{l,r} \cdot wagedist_{l,j,r})^{(1-\sigma^{l}_{j,r})}\right]^{1/(1-\sigma^{l}_{j,r})} \quad (A.4.)$$

$KE_{j,c,r}$ is produced by the aggregate energy input $E_{j,c,r}$ and the capital-land bundle $KT_{j,c,r}$. Its price, $PKE_{j,c,r}$ is the unit cost, and demand for $E_{j,c,r}$ and $KE_{j,c,r}$ are specified as component demand functions.

B.3.4. *Bottom level*

$KT_{j,c,r}$ is aggregated over $K_{j,c,r}$ and $T_{j,c,r}$, i.e. capital and land inputs. Its price, $PKT_{j,c,r}$ is the unit cost. Demand for $K_{j,c,r}$ and $T_{j,c,r}$ are specified as component demand functions.

The energy input, $E_{j,c,r}$, is aggregated over six types of base fuel components. Its price, $PEn_{j,c,r}$ is specified as a unit cost function. The demands for six types of base fuel components, $XAP_{e,j,c,r}$ are specified as corresponding component demand functions.

B.4. *Income distribution and demands*

Income generated from production is distributed to enterprises, households and government. Define $KY_r=\sum R_r\ K_{i,c,r}$, $TY_r=\sum PT_r\ T_{i,c,r}$, $LY_{l,r}=\sum wagedist_{l,i,r}W_{l,r}\ LD_{l,i,c,r}$, as total earnings of capital, land and labor, respectively, where R_r is the rent of capital by region, PT_r is the rent of land by region, $wagedist_{l,i,r}$ is a sectoral distortion coefficient by labor type and regions, $W_{l,r}$ is the average wage by labor types and regions.

B.4.1. *Corporate earnings and savings*

Corporate income is defined as

$$\begin{aligned} CY_r = s_r KY_r &+ \sum_{i,c} \tau^{e}_{i} PE_{i,c,r} ES_{i,c,r} \\ &+ \sum_{i} WPM_{i,o} NTB_i \left(\sum_{r} XM_{i,o,r} - TM_{i,o}\right) ER \\ &\times \left(XM_{i,o,r} / \sum_{r} XM_{i,o,r}\right) \end{aligned} \quad (A.5.)$$

where s_r is the share of capital owned by enterprises, $PE_{i,c,r}$ is the domestic price of exports, $ES_{i,c,r}$ is the supply of exports, $WPM_{i,o}$ is the world price of ordinary imports, $XM_{i,o,r}$ is the ordinary imports, TM_i is the above-quota imports for commodities subject to tariff-rate quota (TRQ)[13] , ER is exchange rate, τ^{e}_{i} is the export tax equivalent rate of the MFA quota for exports of textile and apparels, and NTB_i is the tariff equivalent rate of import quotas, which apply to ordinary import only. $XM/\Sigma XM$ means that the income of import quota rent is distributed between two regions according to their ordinary imports. The corporate income tax revenue and corporate saving can be calculated as

$$TAX^{c}_{g,r} = \tau^{c}_{g,r} CY_r \quad (A.6.)$$

$$SAV^{c}_{r} = \left(1 - \sum_{h} \phi^{c}_{h,r}\right)\left(1 - \sum_{g} \tau^{c}_{g,r}\right) CY_r \quad (A.7.)$$

where $\tau^{c}_{g,r}$ is the corporate income tax rate, $\phi^{c}_{h,r}$ is the share of corporate income distributed to household type h.

[13] TM_i is zero when import is less than the quantity of imports quota, TRQ_i.

B.4.2. *Household income*

Let $TAX^{h}_{g,h,r}=\tau^{h}_{g,h,r}YH_{h,r}$ define the household income tax and $TR^{g}_{g,h,r}$ and $TR^{f}_{h,r}$ define transfer payments from the government and the rest of the world, respectively. The $YH_{h,r}$, income of household type h, and $YD_{h,r}$, disposable income of household type h, can be calculated as

$$\begin{aligned} YH_{h,r} = &\sum_{l} WDIST_{h,l,r} LY_{l,r} + tdist_{h,r} TY_r + \phi^{k}_{h,r}(1 - s_r) KY_r \\ &+ \phi^{c}_{h,r}\left(1 - \sum_{g} \tau^{c}_{g,r}\right) CY_r + CPI_r \cdot \sum_{g} TR^{gh}_{g,h,r} \\ &+ ER \cdot TR^{f}_{h,r} \end{aligned} \quad (A.8.)$$

$$YD_{h,r} = \left(1 - \sum_{g} \tau^{h}_{g,h,r}\right) YH_{h,r} \quad (A.9.)$$

where Pindex is the GDP deflator. The distributional coefficients sum to one, $\sum WDIST=\sum tdist=\sum \phi^{k}=1$. TR^{g} is fixed in real terms and is multiplied by an appropriate price index to preserve model homogeneity. TR^{f} is fixed in international currency terms, and is multiplied by the exchange rate, ER, to convert it into local currency terms.

Household income is the sum of labor income, land return, capital return, distributed enterprise profits, as well as transfers from the government and rest of the world. Rural households earn their labor income from rural sectors and from urban sectors as temporary migrants from the rural area, while urban households obtain their wages from urban sectors only.[14] Household disposable income is defined as after-tax income.

B.4.3. *Government revenue and spending*

Government revenue, GREV, is the sum of all types of tax minus all types of governmental transfers. On- and off budget items are subsumed into one regional government budget. The indirect tax and subsidies PITX, the tariff revenue YTrade and GREV can be calculated as

$$PITX_r = \sum_{i,c} (\tau^{p}_{i,c,r} - \tau^{s}_{i,c,r}) PX_{i,c,r} XP_{i,c,r} \quad (A.10.)$$

$$\begin{aligned} YTrade_r = ER &\sum_{i} WPM_{i,o} \\ &\times \left(\tau^{m}_{i} XM_{i,o,r} + NTB_{i,o} TM_{i,o} \cdot \left(XM_{i,o,r} \sum_{r} XM_{i,o,r}\right)\right) \end{aligned} \quad (A.11.)$$

$$\begin{aligned} GREV_r = TAX^{c}_{r} &+ \sum_{h} TAX^{h}_{h,r} + PITX_r + YTrade_r \\ &- CPI_r \cdot TR^{gh}_{h,r} - ER \cdot TR^{gf}_{r} - Pindex \cdot TR^{gg}_{r} \end{aligned} \quad (A.12)$$

In the above, $\tau^{p}_{i,r}$, $\tau^{s}_{i,r}$ and $\tau^{m}_{i,r}$ are the rates of indirect tax, production subsidy and tariff for good i. $TR^{gh}_{h,r}$, TR^{gf}_{r} and TR^{gg}_{r} are the governmental transfer to households, the rest of the world and the government in rest of China. CPI_r and Pindex are the consumer price index by regions and aggregated price index.

[14] $WDIST_{l,h,r}$ is an endogenous variable determined by the temporary labor migrants between rural and urban area.

Government expenditure, GEXP, is defined as government spending on composite goods.

$$\mathrm{GEXP}_r = \sum_i \mathrm{PAfd}_{i,r}\mathrm{XAFD}^g_{i,r} \quad (A.13.)$$

where $\mathrm{PAfd}_{i,r}=\mathrm{PA}_{i,r}$, defines the final demand price for composite good *i*.

B.4.4. Household demand and saving

We assume households maximize utility using the extended linear expenditure system (ELES), which is an extension of the Stone–Geary demand system. Saving enters the utility function. The price of savings is indicated by the consumer price index, representing the opportunity cost of giving up current consumption in exchange for future consumption (Wang and Kinsey, 1994). Household demand for composite goods i, $\mathrm{XAC}_{i,h,r}$, and saving, $\mathrm{SAV}^h_{h,r}$, are specified as

$$\mathrm{XAC}_{i,h,r} = \mathrm{Pop}_{h,r}\theta_{i,h,r} + \mu_{i,h,r}\mathrm{Y}^*_{h,r}/\mathrm{PC}_{i,r} \quad (A.14.)$$

$$\mathrm{Y}^*_{h,r} = \mathrm{YD}_{h,r} - \mathrm{Pop}_{h,r}\sum_i \mathrm{PC}_{i,r}\theta_{i,h,r} \quad (A.15)$$

$$\mathrm{SAV}^h_{h,r} = \mathrm{YD}_{h,r} - \sum_i \mathrm{PC}_{i,r}\mathrm{XAC}_{i,h,r} \quad (A.16)$$

where $\theta_{i,h,r}$ denotes "subsistence" consumption, which is assumed to be zero for households savings. $\mu_{i,h,r}$ is the marginal budget share and $\mathrm{Y}^*_{h,r}$ is the supernumerary income. $\mathrm{PC}_{i,r}=\mathrm{PA}_{i,r}$, defines the consumer price for composite good i.

B.4.5. Other final demands

Other final demands, namely investment, and changes in stocks, are specified as fixed share Leontief functions of total final demand.

$$\mathrm{XAFD}_{i,f,r} = \alpha^f_{i,f,r}\mathrm{TFD}_{f,r} \quad (A.17)$$

$$\sum_i \mathrm{PAfd}_{i,r}\mathrm{XAFD}_{i,f,r} = \mathrm{TFDV}_{f,r} \quad (A.18)$$

where $\mathrm{XAFD}_{i,f,r}$ is the demand for commodity *i* by final demand *f* and by regions. $\mathrm{TFD}_{f,r}$ is the total demand and $\mathrm{TFDV}_{f,r}$ is the corresponding expenditure. $\alpha^f_{i,f,r}$ is the fixed-share parameter.

B.5. Foreign trade

B.5.1. Exports and domestic supply

Output of ordinary firms, $\mathrm{XP}_{i,o,r}$ is sold on the domestic market ($\mathrm{XDS}_{i,r}$) or exported to the rest of the world ($\mathrm{ESR}_{i,o,r}$) to maximize firm revenue, according to a constant elasticity of transformation (CET) function. The output price, $\mathrm{PP}_{i,r}$, is specified as a unit revenue function that has a format similar to Eq. (A.2) and the supplies of $\mathrm{XDS}_{i,r}$ and $\mathrm{ESR}_{i,o,r}$ are the corresponding component supply functions whose formats are similar to Eq. (A.3). However, the elasticity of transformation, σ_r, is negative here. The difference between $\mathrm{PP}_{i,r}$ and $\mathrm{PX}_{i,r}$ is the sectoral indirect tax rate, $\tau^p_{i,r}$ net of production subsidy rate, $\tau^s_{i,r}$. Similarly, domestic supply ($\mathrm{XDS}_{i,r}$) is divided into local market supply ($\mathrm{XD}_{i,r}$) and interregional export to the rest of China ($\mathrm{XDE}_{i,r}$).

Output of export processing firms, $\mathrm{XP}_{i,p,r}$ is assumed to be exported only, i.e.

$$\mathrm{XP}_{i,p,r} = \mathrm{ESR}_{i,p,r} \quad (A.19.)$$

China's export supply by trade regime is a CES aggregate of the two regional export supplies, i.e. $\mathrm{ES}_{i,c}$ is aggregated over two regional export supply, $\mathrm{ESR}_{i,c,r}$. We assume the buyers of rest of the world choose a mix between the ordinary exports, $\mathrm{ES}_{i,o}$ and processing exports, $\mathrm{ES}_{i,p}$ to minimize their cost. The aggregate exports, ED_i is the CES aggregation of the two types of exports. The price of aggregate exports, WPE_i is specified as unit cost function similar to Eq. (A.2) and measured in domestic currency, while demands for $\mathrm{ES}_{i,o}$ and $\mathrm{ES}_{i,p}$ are specified as component demand functions similar to Eq. (A.3).

Exports are demanded according to constant-elasticity demand curves. We choose high price-elasticities to reflect the limited price influence power of China's exports. $\overline{\mathrm{WPINDEX}}_i$ refers to World Export Price.

$$\mathrm{ED}_i = \alpha^e_i\left(\frac{\mathrm{ER}\,\overline{\mathrm{WPINDEX}}_i}{\mathrm{WPE}_i}\right)^{\sigma^e_i} \quad (A.20.)$$

B.5.2. Imports

Products are assumed to be differentiated by region of origin, i.e. the Armington assumption (Armington, 1969). "Foreign" counts as one region. A two-level nested CES aggregation function is specified for each Armington composite commodity. At the top level, the Armington composite good, $\mathrm{XA}_{i,r}$, is an aggregation of domestically produced goods sold on the domestic market, $\mathrm{XDA}_{i,r}$, and aggregate imports, $\mathrm{XMA}_{i,r}$, according to cost minimization. Its price, $\mathrm{PA}_{i,r}$, is specified as the unit cost function, while demands for $\mathrm{XDA}_{i,r}$ and $\mathrm{XMA}_{i,r}$ are specified as component demand functions similar to Eqs. (A.2) and (A.3). At the second level of the nest, the import aggregate $\mathrm{XMA}_{i,r}$ is further split into ordinary import, $\mathrm{XM}_{i,o}$ and duty-free import of investment goods for foreign invested enterprises and export processing enterprises, $\mathrm{XM}_{i,z}$. The price of aggregate imports, $\mathrm{PMA}_{i,r}$, is specified as the unit cost function, and demands for $\mathrm{XM}_{i,o}$ and $\mathrm{XM}_{i,z}$ are specified as component demand functions. At the same level of the nest, the aggregate domestic good is split into a local good ($\mathrm{XD}_{j,r}$) and interregional import from the rest of China ($\mathrm{XDM}_{j,r}$).

The imports of duty-free processing goods, $\mathrm{XM}_{i,p,r}$ are used as intermediate inputs of export processing firms, i.e.

$$\mathrm{XM}_{i,p,r} = \sum_j \mathrm{XAP}_{i,j,p,r} \quad (A.21.)$$

The prices of the three types of imports, $\mathrm{WPM}_{i,m,r}$ are exogenous in foreign currency (an infinite price-elasticity).

We establish the difference between domestic price and world price in two parts, i.e. the tariff rate and non-tariff barriers. NTB is modeled as the tariff equivalent that creates a pure rent to enterprises. The quantitative restrictions/quotas are modeled explicitly. Either they are modeled through a binding constraint where imports cannot exceed the quota allocation and the rates of quota rent, NTBs, are solved endogenously to clear the market, or they are modeled via a tariff-rate quota system formulated as a mixed complementarity problem (MCP). In the latter case, both the rates of quota rent, NTB and over-quota import, TM_i are endogenous, i.e. whether the quota is binding or not is endogenously determined by the model. The rate of quota rent is equal to the exogenous above quota tariff. Eqs. (A.21) and (A.22) define the complementarity-slackness conditions:

$$XM_{i,o} - TM_i \le TRQ_i,\ NTB_i \ge 0,\ NTB_i(TRQ_i - XM_{i,o} + TM_i) = 0 \quad (A.22)$$

$$NTB_1 + \tau_i^m \le \tau h_i^m,\ TM_i \ge 0,\ TM_i(\tau h_i^m - NTB_i - \tau_i^m) = 0 \quad (A.23)$$

In the above TRQ_i is the import quota quantity, τ_i^m and τh_i^m are the within-quota tariff rate and over-quota tariff rate, respectively. In each equation, at least one of the two inequalities must be satisfied as a strict equality, i.e., either the rate of quota rent equals zero or imports equals the sum of import quota TRQ_i and over-quota imports TM_i, and either over-quota imports equals zero or the rate of quota rent equals to over-quota tariff rate minus in-quota tariff rate.

B.6. *Labor market*

The model assumes imperfect labor mobility between agricultural and production workers. A CET function is used to capture the mobility, i.e., it is determined by the relative wage of agricultural workers and production workers, as well as by the constant elasticity of transformation.

$$LS_{agl,r} = \gamma_{agl,r}\left(\frac{W_{agl,r}}{RAW_r}\right)^{\sigma^{ag}} TL_r^{agusk} \quad (A.24)$$

$$LS_{usk,r} = \gamma_{usk,r}\left(\frac{W_{usk,r}}{RAW_r}\right)^{\sigma^{ag}} TL_r^{agusk} \quad (A.25)$$

$$LS_{skl,r} = L^b_{skl,r} \quad (A.26)$$

$$RAW_r = \left[\gamma_{agl,r} W_{agl,r}^{1-\sigma^{ag}} + \gamma_{usk,r} W_{usk,r}^{1-\sigma^{ag}}\right]^{1/(1-\sigma^{ag})} \quad (A.27)$$

where $LS_{l,y}$ is labor supply of agri- and unskilled, $W_{agl,r}$ and $W_{usk,r}$ are the wages of agricultural- and production worker, TL^r_{agusk} is aggregate supply of labor (agri-and unskilled), and RAW_r is economy-wide average wage.

B.6.1. *Interregional labor migration*

The model assumes imperfect interregional factor mobility. CET functions are utilised to describe the regional movement of labor. The movement of labor is determined by the relative real income and the constant elasticity of transformation. The real income of labor is defined as the wage plus per capita net governmental transfer income, deflated by the regional consumer price indices.

$$L^b_{l,GD} = \xi_{l,GD}\left(\frac{PW_{l,GD}}{APW_l}\right)^{\sigma^{lm}} \overline{TL}^{gdroc}_{l,r} \quad (A.28)$$

$$L^b_{l,ROC} = \xi_{l,ROC}\left(\frac{PW_{l,ROC}}{APW_l}\right)^{\sigma^{lim}} \overline{TL}^{gdroc}_{l,r} \quad (A.29)$$

$$TL_r^{agusk} = L^b_{ag,r} + L^b_{usk,r} \quad (A.30)$$

$$PW_{l,r} = \left(W_{l,r} + \sum_h (TR^{gh}_{h,r} \cdot CPI_r) / \sum_h (\overline{POP}_{h,r})\right) / CPI_r \quad (A.31)$$

$$APW_l = \left[\xi_{l,GD} PW_{l,GD}^{1-\sigma^{lm}} + \xi_{l,ROC} PW_{l,ROC}^{1-\sigma^{lm}}\right]^{l/(1-\sigma^{lm})} \quad (A.32)$$

where $L^b_{l,r}$ are labor supplies before interregional labor migration. $PW_{l,r}$ is the real income of labor. $\overline{TL}^{gdroc}_{l,r}$ is (exogenous) aggregate supply of labor (Guangdong- and Rest of China), and APW_l is the economy-wide average income (wage and tariffs).

B.7. *Environmental feature of the model*

B.7.1. *Emissions*

In the two regions CGE model, the amount of a given polluting emission (*p*) takes the following form:

$$POL_{j,p,r} = \sum_i (\alpha_{p,i,j} XAP_{i,j,r}) + \beta_{p,j} XP_{j,r} + \gamma_{p,j} XA_{j,r} \quad (A.33)$$

Where, $POL_{j,p,r}$ is the emission level of a given polluting emission (*p*) by sector and region, $\alpha_{p,i,j}$ is the emission volume associated with one unit consumption of commodity *i* used by sector *j*; $\beta_{p,j}$ the emission volume associated with one unit production of sector *j*. $\gamma_{p,j}$ the emission volume associated with one unit consumption of product *j* in final consumption . Thus, the first two elements of the right-hand side expression represent supply-related emissions, the third one final-demand-related emissions.

B.7.2. *Health benefit*

Based on the emission change calculated by Eq. (A.25), the model evaluates the health benefit in three steps. In the first step, the model introduces dispersion functions to estimate impacts on air pollution exposure of emission change:

$$CON_{p,r} = incon_{p,r} + \sum_{stck,j} dcon_{stck,p,r}\, map_{stck,p,r} POL_{j,p,r} \quad (A.34)$$

Where $CON_{p,r}$ refers to the ambient pollution concentration, $incon_{p,r}$ is a constant reflecting background emissions' contribution to concentrations, $dcon_{stck,p,r}$ are dispersion coefficients linking emissions to concentration, $map_{stck,j}$ accounts for the height of emission sources.

In the second step, the model introduces dose–response function to estimate impacts on health risk end-points.

$$DISE_{d,r} = \sum_p dose_{d,p} CON_{p,r} pop_r \quad (A.35)$$

Where, $DISE_{d,r}$ refers to number of disease case, $dose_{d,p}$ is a disease coefficient linking disease with concentrations. pop_r is population by regions.

In the last step, the model introduces monetary value of unit changes in various health endpoints to estimate values of health risk end-points.

$$DAMA_r = \sum_d adj_r vuc_d DISE_{d,r} \quad (A.36)$$

Where, $DAMA_r$ refers to monetary values of health risk end-points, vuc_d is monetary value of unit changes in various health endpoints. adj_r is adjustment factor for vuc_d by regions.

B.8. *Equilibrium and macro closure*

B.8.1. *Equilibrium in the composite good market*

Household consumption, other final demands, the intermediate inputs of ordinary firms and part of intermediate inputs of processing firms[15] constitute the total demand for an Armington composite good.

$$XA_{i,r} = \sum_j XAP_{i,j,o,r} + \sum_j XAP^d_{i,j,p,r} + \sum_h XAC_{i,h,r} + \sum_j XAFD_{i,f,r} \quad (A.37)$$

B.8.2. *Equilibrium in the factor markets*

Define TS as the fixed total supply of land and KS as the capital stock. Capital, land and labor market clearing condition can be specified as follows:

$$TS_r = \sum_{i,c} T_{i,c,r} \quad KS_r = \sum_{i,c} K_{i,c,r} \quad LS_{i,c} = \sum_{i,c} LD_{l,i,c,r} \quad (A.38)$$

B.8.3. *Macro closure*

Define SAV^g_r as government saving, SAV^f_r as the balance of payments. Then the following three macroeconomic identities hold:

Government budget:

$$SAV^g_r = GREV_r - GEXP_r \quad (A.39)$$

SAV^g_r is endogenously determined.

Saving and investment: $TFD_{inv,r}$ is the real fixed asset investment and PI_r is the price index of fixed asset investment; $TFDST_{st,r}$ is the real change in stocks and PST_r is the price index of changes in stocks.

$$TFD_{inv,r} \cdot PI_r + TFD_{st,r} \cdot PST_r = SAV^c_r + SAV^g_r + \sum_h SAV^h_{h,r} + ER\ SAV^f_r \quad (A.40)$$

Balance of payments:

$$SAV^f_r = \sum_{i,m} WPM_{i,m,r} XM_{i,m,r} + ER \cdot TR^{gf}_r - \sum_h TR^f_{h,r} - \sum_i WPE_{i,r} ES_{i,r}/ER \quad (A.41)$$

The foreign saving or current account, $TSAV^f\ (= \sum_r SAV^f_r)$ is fixed in foreign currency terms and the real exchange rate is endogenous to balance the current account. In this model, the aggregate investment is the endogenous sum of the separate saving components. This specification corresponds to the "neoclassical" macroeconomic closure in CGE literature.

B.9. *Recursive dynamics*

The model has a simple recursive dynamic structure. Dynamics in the model originate from accumulation of productive factor and productivity changes. The base year of the data and the model is 1997. The model is solved for subsequent years from 1998 to 2010. The time periods are linked together through factor growth (labor/land) and accumulation (capital), and change in productivity.

The growth of land, labor, population and productivity are exogenous. The growth of capital is endogenously determined by the saving/investment relation. Define δ as the depreciation rate, the capital stock in year t can be calculated as

$$KS_t = (1-\delta)KS_{t-1} + TFD_{inv,t-1} \quad (A.42)$$

[15] The following are the assumptions that we made in the construction of two-regime SAM: For the intermediate input of production of processing export, we assume that the input from non-tradable goods (such as service and electricity) and primary goods (such as agriculture goods, food, and mineral products) are provided by domestic production and imports of processing trade. And all the other intermediate input in production for processing export are provided by import of processing trade.

REFERENCES

Armington, P., 1969. A theory of demand for products distinguished by place of production. IMF Staff Papers 16, 159–178.

Aunan, K., Li, S., 1999. Health damage assessment for Guangzhou using exposure–response functions. Technical Report B7. Air Quality Management and Planning System for Guangzhou. NILU, Kjeller, Norway.

Aunan, K., Berntsen, T., O'Connor, D., Persson, T.H., Vennemo, H., Zhai, F., 2007. Benefits and costs to China of a climate policy. Environment and Development Economics 12 (3).

Bach, C., Martin, W., Stevens, J., 1996. China and the WTO: tariff offers, exemptions and welfare implications. Weltwirtschaftliches Arkiv 132 (3), 409–431.

Bhattasali, D., Li, S., Martin, W. (Eds.), 2004. China and the WTO: accession, policy reform and poverty reduction strategy. Oxford University Press.

Bond, T.C., Streets, D.G., Yarber, K.F., Nelson, S.M., Woo, J.-H., Klimont, Z., 2004. A technology-based global inventory of black and organic carbon emissions from combustion. Journal of Geophysical Resources 109, D14203. doi:10.1029/2003JD003697.

Borjas, G.J., 2003. The labor demand curve is downward sloping: reexamining the impact of immigration on the labor market. Quarterly Journal of Economics 1335–1374 (November).

CCICED, 2004. An environmental impact assessment of China's WTO-accession: an analysis of six sectors. International Institute for Sustainable Development, Winnipeg, Canada. http://www.iisd.org/trade/cciced/taskforce_documents.asp.

Cheng, L., Shen, X., Gong, J., Jiang, Y., Pan, F., 2004. Textiles, in CCICED (2004): *an environmental impact assessment of China's WTO-accession: An analysis of six sectors*. International Institute for Sustainable Development, Winnipeg, Canada. http://www.iisd.org/trade/cciced/taskforce_documents.asp.

Chun, C., Fleisher, B., Parker, E., 2001. The impact of China's entry into the WTO: overview. China Economic Review 11 (4), 319–322.

Cofala, J., Amann, M., Mechler, R., (2005). Scenarios of world anthropogenic emissions of air pollutants and methane up to 2030, mimeo, International Institute for Applied System Analysis (IIASA), Laxenburg, Austria. http://www.iiasa.ac.at/rains/global_emiss/Global%20emissions%20of%20air%20pollutants%20.pdf.

Copeland, B.R., Taylor, M.S., 2004. Trade, growth and the environment. Journal of Economic Literature 42, 7–72 (March).

de Melo, J., 1988. Computable general equilibrium models for trade policy analysis in developing countries: a survey. Journal of Policy Modelling 10 (4).

de Melo, J., Winters, L.A., 1993. Do exporters gain from VERs? European Economic Review 37, 1331–1349.

Dean, J.M., 2002. Testing the impact of trade liberalisation on the environment: theory and evidence. Canadian Journal of Economics 35 (4), 819–842.

Dervis, K., de Melo, J., Robinson, S., 1982. General equilibrium models for development policy. Cambridge University Press, Cambridge.

Dessus, S., Roland-Holst, D., van der Mensbrugge, D., 1994. Input-based pollution estimates for environmental assessment in developing countries. OECD Development Centre Technical Paper, vol. 101. OECD, Paris.

Diewert, W.E., 1982. Duality approaches to microeconomic theory. In: Arrow, K.J., Intriligator, M.D. (Eds.), Handbook of Mathematical Economics, vol. II. Chapter 12.

FAO, 2002. Fertilizer use by crop, Food and Agriculture Organization of the United Nations, Fifth edition. Rome.

Fewsmith, J., 2001. The political and social implications of China's accession to the WTO. China Quarterly 167, 573–591.

Fisher-Vanden, K., Jefferson, G.H., Liu, H., Tao, Q., 2004. What is driving China's decline in energy intensity? Resource and Energy Economics 26, 77–97.

Fisman, R., Wei, S.-J., 2004. Tax rates and tax evasion: evidence from "missing imports" in China. Journal of Political Economy 112 (2), 471–496.

Francois, J.F., Spinanger, D., 2004. WTO accession and the structure of China's motor vehicle sector. In: Bhattasali, D., Li, S., Martin, W. (Eds.), China and the WTO: Accession, policy reform and poverty reduction strategy. Oxford University Press, pp. 191–211.

Garbaccio, R.F., Ho, M.S., Jorgenson, D.W., 2000. The health benefits of controlling carbon emissions in China. In: OECD (Ed.), Proceedings of a workshop on assessing the ancillary benefits and costs of greenhouse gas mitigation strategies. OECD, Paris.

Gilbert, J., Wahl, M., 2002. Applied general equilibrium assessments of trade liberalisation in China. World Economy 25 (5), 697–731.

Grossman, G.M., Krueger, A.B., 1993. Environmental impacts of a North American free trade agreement. In: Garber, P.M. (Ed.), The U.S.-Mexico Free Trade Agreement. MIT Press, Cambridge, USA.

He, J., 2005. Estimating the economic cost of China's new desulfur policy during her gradual accession to WTO: the case of industrial SO_2 emission. China Economic Review 16, 364–402.

Hertel, T.W., Zhai, F., 2006. Labor market distortions, rural–urban inequality and the opening of China's economy. Economic Modelling 23, 76–109.

Hertel, T.W., Zhai, F., Wang, Z., 2004. Implications of WTO accession for poverty in China. In: Bhattasali, D., Li, S., Martin, W. (Eds.), China and the WTO: Accession, policy reform and poverty reduction strategy. Oxford University Press.

Hu, T., 2004. Agriculture, in CCICED (2004): an environmental impact assessment of China's WTO-accession: an analysis of six sectors. International Institute for Sustainable Development, Winnipeg, Canada. http://www.iisd.org/trade/cciced/taskforce_documents.asp.

Ianchovichina, E., Martin, W., 2001. Trade liberalisation and China's accession to WTO. Journal of Economic Integration 16 (4), 421–445.

Jiang, K., Hu, X., Guo, D., Cheng, L., 2004. Energy, in CCICED (2004): an environmental impact assessment of China's WTO-accession: an analysis of six sectors. International Institute for Sustainable Development, Winnipeg, Canada. http://www.iisd.org/trade/cciced/taskforce_documents.asp.

Lardy, N., 2002. Integrating China into the global economy. Brookings Institutions Press, Washington DC.

Liu, J.-T., Hammitt, J.K., 1999. Perceived risk and value of workplace safety in a developing country. Journal of Risk Research 2 (3), 263–275.

Lvovsky, K., Hughes, D., Maddison, D., Ostro, D., Pearce, D., 2000. Environmental costs of fossil fuels: a rapid assessment method with application to six cities. The World Bank Environment Department, Washington, DC.

Martin, W., Ianchovichina, E., 2001. Implications of China's accession to the World Trade Organisation for China and the WTO. World Economy 24 (9), 1205–1219.

McKibbin, J.W, Tang, K.K., 2000. Trade and financial reform in China: impacts on the world economy. World Economy 23 (8), 979–1003.

Naughton, B., 1996. China's emergence and prospects as a trading nation. Brookings Papers on Economic Activity 2, 273–338.

NBS, 2006. China statistical yearbook 2006. China Statistics Press, Beijing.

O'Connor, D., Zhai, F., Aunan, K., Berntsen, T., Vennemo, H., 2003. Agricultural and human health impacts of climate policy in China: a general equilibrium analysis with special reference to Guangdong. OECD Development Centre Technical Paper, vol. 206. OECD, Paris.

Olivier, J.G.J., Berdowski, J.J.M., 2001. Global emissions sources and sinks. In: Berdowski, J., Guicherit, R., Heij, B.J. (Eds.), The Climate System. A.A. Balkema Publishers/Swets & Zeitlinger Publishers, Lisse, The Netherlands. ISBN: 90 5809 255 0, pp. 33–78.

Panditchpakdi, S., Clifford, M., 2002. China and the WTO: changing China, changing world trade. John Wiley & Sons, Singapore.

Vennemo, H., 1990. Optimal taxation in applied general equilibrium models adopting the Armington assumption. Discussion Paper, vol. 55. Statistics Norway, Oslo.

Wang, Z., 2003. The impact of China's WTO-accession on patterns of world trade. Journal of Policy Modelling 25, 1–41.

Wang, Z., Kinsey, J., 1994. Consumption and saving behavior under strict and partial rationing. China Economic Review 5, 83–100.

WHO (1989): Management and control of the environment, WHO/PEP/89.1, Geneva.

World Bank, 1994. China foreign trade reform. World Bank Country Study. World Bank, Washington, DC.

World Bank, 1997. Clear water, blue skies: China's environment in the new century. Washington, DC.

World Bank, 2001. New countermeasures for air pollution control in China, cd-rom attachment to World Bank: *China Air Land and Water*, Washington, DC.

WTO, 2003. *International trade statistics 2003*, World Trade Organisation, Geneva. http://www.wto.org/english/res_e/statis_e/its2003_e/its03_toc_e.htm.

Zhai, F., Li, S., 2000. The implications of accession to WTO on China's economy. Paper Presented at the Third Annual Conference on Global Economic Analysis, Melbourne, Australia, June 27–30.

Zhang, X., 2002. Valuing mortality risk reductions using the contingent valuation method: Evidence from a survey of Beijing residents in 1999. Paper Presented at the Second World Congress of Environmental Economists, Monterrey, California, June 2002.