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Assessing economic impacts of China's water pollution mitigation measures through a dynamic computable general equilibrium analysis

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Abstract
In this letter, we apply an extended environmental dynamic computable general equilibrium model to assess the economic consequences of implementing a total emission control policy. On the basis of emission levels in 2007, we simulate different emission reduction scenarios, ranging from 20 to 50% emission reduction, up to the year 2020. The results indicate that a modest total emission reduction target in 2020 can be achieved at low macroeconomic cost. As the stringency of policy targets increases, the macroeconomic cost will increase at a rate faster than linear. Implementation of a tradable emission permit system can counterbalance the economic costs affecting the gross domestic product and welfare. We also find that a stringent environmental policy can lead to an important shift in production, consumption and trade patterns from dirty sectors to relatively clean sectors.

Keywords: environmental computable general equilibrium, water pollution, tradable emission permits, emission reduction target, environmental policy

1. Introduction

The price of economic success in China has been the over-exploitation of natural resources and huge impacts on the environment, particularly water resources. With the rapid economic growth and change in lifestyles, disposal of hazardous and municipal waste, discharge of industrial and municipal wastewater, and agricultural runoff containing fertilizers, pesticides and manure have all contributed to polluting most of China's surface water and groundwater, thus reducing the country's available water resources. In 2007, only 59.5% of river sections, 48.9% of lakes, 78.5% of reservoirs, and 37.5% of groundwater wells met quality criteria for source water supply (MWR 2008). Owing to severe pollution, even southern parts of China, with their relatively well-stocked resources, face shortages of safe clean drinking water.

To mitigate the impact of water pollution, a series of pollution control policies have been adopted in China. When

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discharging wastewater, polluters are required to meet rigid discharge standards. However, with the enlargement of China's economy, total pollutant emission is still increasing and exceeds the assimilation capacity of many water bodies, thus diminishing water quality. This is especially severe in the north of China.

Given the serious impacts of water pollution, both the general public and the Chinese government have gradually become more aware of the importance of taking stronger action to control the total amount of emissions. In *The Eleventh Five-Year Plan for National Social and Economic Development* (SCCG 2006), a strict total emission reduction target—10% chemical oxygen demand (COD) reduction in 2010 based on 2005 benchmark data—was set by central government. Local governments were required to proportionately reduce their COD emission by 10% in 2010. Increasing attention is also being paid by both central government and some local governments to total emission control of ammonia nitrogen (NH_3–N) and other main pollutants. When implementing the total emission reduction target, local governments not only invest in end-of-pipe and process-integrated measures but also attempt to adopt tradable emission permit systems to trade emission rights, thereby reducing the abatement cost of reducing pollutant emission. Several environment permit exchange centers have been established by local governments in places such as Beijing, Shanghai and Tianjin.

Effective water pollution control policies could yield multiple benefits, including the protection of both the natural environment and human health, improved water quality for various uses, and the alleviation of water shortages. Unfortunately, many environmental policies also impact economic growth, poverty, employment or income distribution. The complexity of the direct and indirect relationships between economic, environmental and social variables calls for tools for quantitative environmental and economic analysis that enable the effectiveness of pollution controls and the economic and welfare impacts of these policies to be evaluated.

The aim of this letter is to examine the effectiveness of total emission control policies in China and to assess the impacts of emission reduction targets on macroeconomic, sectoral, social variables, using an extended environmental dynamic computable general equilibrium (CGE) model. This is the first time that a dynamic CGE framework has been applied to analyze the direct and indirect economic impacts of China's water pollution control targets, an understanding of which is expected to generate useful insights for water pollution control strategies.

2. Dataset and methodology

2.1. Description of the model

Following the methodology proposed by Dellink *et al* (2003), the model is developed by using the mathematical program system for general equilibrium (MPSGE), which is a general algebraic modeling system (GAMS) extension developed by Rutherford (1998), with the MCP GAMS solver. A diagrammatic overview of the main structure of the model is presented in figure 1. For the main equations for the model, refer to Dellink (2000, 2005), Dellink *et al* (2003) and Dellink and van Ierland (2006). We give only a general description of the model.

The production module of the model consists of 27 production sectors. It is assumed that each sector produces one kind of good and all sectors make production decisions in accordance with the principle of constant returns to scale to minimize production costs. Each level of production is determined by a multi-level nested production function, which consists of factor endowments, intermediate inputs, pollution permits and abatement services. Factors are assumed to be freely mobile across sectors and an exogenous growth of the annual labor supply, in terms of both population and technological efficiency, is assumed to drive the growth of the economy. The model assumes imperfect substitution between goods differing in origin or destination. The constant elasticity of transformation (CET) function is used to formalize this concept of imperfect substitution between domestic consumption of sectoral output and foreign demands. The Armington (1969) CES functional form is used to determine imperfect substitutability between domestic outputs and imported goods.

On the demand side, private households are included as a single representative consumer, receiving income from the sale of their endowments of capital goods and labor, reduced by lump-sum transfer payments to the government. The levels of consumption of different goods and environmental services are combined in a nested constant elasticity of substitution (CES) utility function. The government receives its income from taxation, sales of pollution permits, and lump-sum transfer payments from the household sector.

The model used in this letter is a forward-looking neo-classical growth model, which includes the inter-temporal elasticity lacking in recursive dynamic models. Private households have the foresight to maximize the present value of current and future utility under a budget constraint. A simple growth path is specified in the model by the exogenous growth of labor supply in efficiency units, together with exogenous technical progress. The growth of capital is endogenously determined by the saving/investment ratio. For a detailed description of the dynamic path of the model, we refer the reader to Dellink (2005).

Pollutants are often by-products of the process of production and consumption. Each level of production and consumption in the model is assumed to require some combination of pollution permits and abatement services. Producers and households have the endogenous choice between paying for their emissions and investing in pollution abatement, and will always choose an optimal combination at the least cost (Dellink 2005). Therefore, a substitution exists between them. In the model, it is determined by the pollution abatement substitution (PAS) function, which is a CES-type curve. In Dellink and van Ierland (2004), there is only a simple abatement sector, which provides 'abatement services' for all environmental tasks. We disaggregate this sector into three distinct abatement sectors providing cleanup

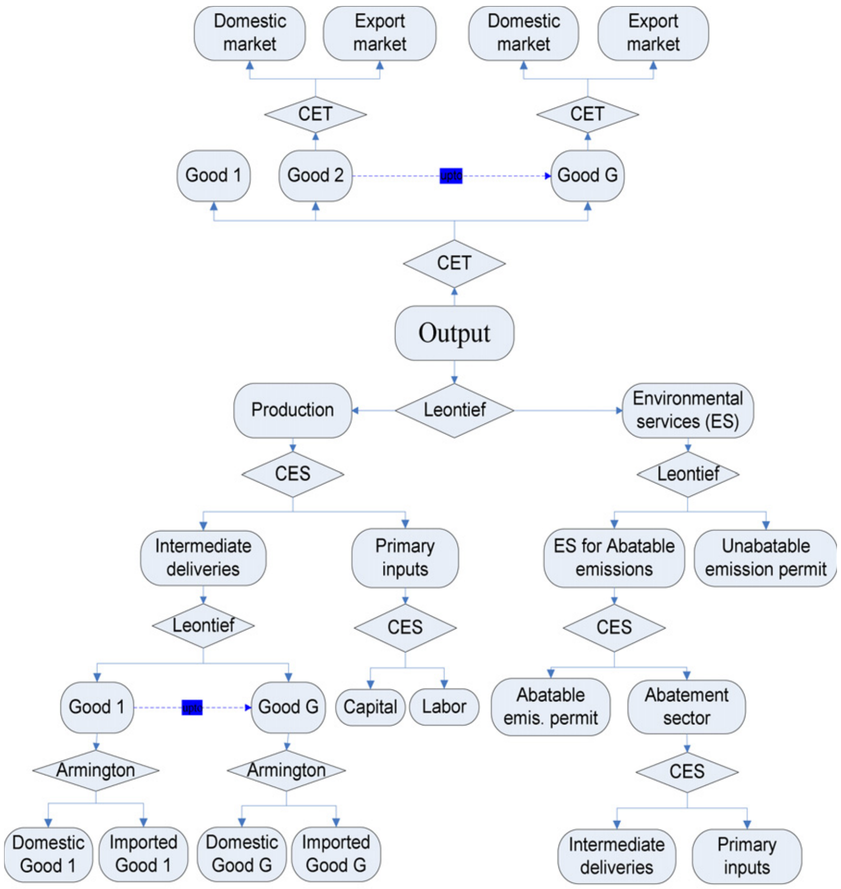

Figure 1. Diagrammatic overview of the main structure of the model.

services for the emission of specific pollutants. A key feature of this extension is that the abatement expenditure captures as much information as possible about the technical measures underlying the options for each pollutant, and gives a more detailed specification of the abatement costs for different pollutants for each production activity. In these abatement sectors, pollution can be abated through end-of-pipe measures and also reduced through process-integrated measures. The agricultural sector in particular depends more on the adaptation of the process-integrated measures for reducing the emission of COD and NH_3–N in the production process.

To simulate the economic consequences of ‘cap and trade’ policy, an emission permit market is created in the model. Total emission levels of pollutants are controlled by the government, who sets the total emission reduction targets exogenously by issuing a restricted number of emission permits. When both the marginal abatement cost and the cost of economic restructuring are higher than the anticipated added value, producers will prefer to reduce their economic activities. This is the third possibility to reduce emission level in the model.

2.2. Dataset: environmental social accounting matrix

A traditional social accounting matrix (SAM) fails to represent elements such as resource use, emission accounts, pollution abatement activities and their interactions with economic activities. Keuning (1993) proposed that pollution impacts should be integrated into a SAM framework and physical environmental accounts should be integrated into a national accounting matrix (NAMEA), but unfortunately ignored pollution abatement activities. Xie (1995) developed an environmentally extended SAM framework (EESAM) that provides an integrated dataset for analyzing pollution abatement sectors, sectoral payments for pollution cleanup, pollution emission taxes, pollution control subsidies and environmental investments. Based on the environmental accounting in NAMEA and the abatement activity accounting in Xie’s EESAM framework, we present an environmental SAM (ESAM) that includes both pollution abatement activity accounts and the corresponding pollution emission accounts. The ESAM captures the interactions between pollution and economic activities and provides a consistent and integrated data framework for calibrating the above model. Its basic structure is shown in table 1.

Our ESAM for the Chinese economy includes 27 production sectors and three pollution abatement sectors—one for COD, one for NH_3–N and one aggregate abatement sector for other pollutants (OHP). The data on activities, commodities, and import and export accounts are based on the national input–output table of China’s economy for the year 2007. The revenue and expenditure accounts for the government come from the *Finance Yearbook of China 2008*

Table 1. Basic structure of ESAM.

		Expenditures											
		Activity		Commodity		Factors							
Receipts		Production	Abatement	Goods	Cleanup	Labor	Capital	Households	Government	Saving-investment	Rest of the world	Total	Emission of pollutants
Activity	Production			Marked outputs								Activity income (gross output)	Production pollution
	Abatement				Cleanup supply								
Commodity	Goods	Intermediate input (use)						Private consumption	Government consumption	Investment	Exports	Total demand	
	Cleanup	Payment for cleaning						Payment for cleaning					
Factors	Labor	Value-added (factor payments)									Factor income		
	Capital												
Household						Factor payments			Subsidies to household		Transfer to household	Household income	Consumption pollution
Government		Indirect taxes		Tariff		Factor taxes		Transfer to government			Transfer to government	Government income	
Savings-investment (S-I)								Household savings	Government savings		Foreign savings	Total savings	
Rest of the World (ROW)				Imports								ROW income	
Total		Total cost		Total absorption		Total factor expenditures		Household expenditures	Government expenditures	Total investment	ROW expenditures		
Pollutants emitted (in physical units)		Pollutants abated or reused											

(MOF 2008) and tax data come from the *Tax Yearbook of China 2008* (SAT 2008). Household and government revenue and expenditure are adjusted based on the flow-of-funds accounts in the *China Statistical Yearbook 2008* (NBS 2008).

Apart from the 27 production sectors, the environmental portion of ESAM includes three pollution abatement sectors—one for COD, one for NH_3–N and one aggregate abatement sector for other pollutants. Cost data for removing pollution in both the production sector and households come from the *Annual Statistical Report on Environment in China 2007* (MEP 2008b). The intermediate demands of abatement sectors on the commodities of production sectors are estimated from the intermediate consumption coefficients of the 'environment management service sector', which can be calculated using the data in the input–output table, which has 135 sectors. All payments from production sectors for pollution abatement or from abatement sectors for intermediate consumption of commodities from production sectors must be deducted from the accounts of activities and commodities when compiling the ESAM. Payments from households for pollution abatement must also be deducted from the accounts of household consumption of the service sector.

To fulfil the row–column constraint, we adopt the cross-entropy method (Robinson and El-Said 2000) to balance the micro-SAM for China, using the GAMS software environment. The simple ESAM developed by the authors for 2007 is shown in table 2.

Data on emission accounts come from *China Environment Bulletin 2007* (MEP 2008a) and the *Annual Statistical Report on Environment in China 2007* (MEP 2008b) and *The First National Pollution Census* (MEP, NBS and MOA 2010). To be consistent with the classifications of abatement sectors, the emission accounts comprise an individual account each for COD and for NH_3–N, and an aggregate account for the other pollutants, most of which are poisonous and noxious substances, including oils, volatile phenol, cyanogens, mercury, cadmium, hexavalent chromium, lead and arsenic. These pollutants are merged into an aggregate emission account by calculating their pollution equivalents (PEs) based on the different damage levels caused to the environment. PE values for each pollutant are shown in table 3, calculated according to the *Effluent Fee Charge Standards and Accounting Method,* which was released by MEP in 2003. Sectoral and consumption emissions for COD, NH_3–N and other pollutants to water for the year 2007 are shown in table 4. The initial pollution permit expenditures are 0.7 CNY kg^{-1} for COD, 0.875 CNY kg^{-1} for NH_3–N, and 0.7 CNY kg^{-1} PEs for other pollutants, respectively.

2.3. Calibration of the model

Owing to the sophistication of the model and data limitations, it is usually difficult to determine all parameters through the econometric method (Gunning and Keyzer 1995). Therefore, parameter values are usually determined by a calibration procedure (Mansur and Whalley 1984). According to the constructed ESAM, the share parameters, such as consumer and government consumption share, average savings rate and average tax rate, are calibrated to benchmark data assumptions for China, whereas the elasticity parameters, such as elasticity of substitution between production factors, Armington elasticity and CET, are all fixed exogenously based on previous studies (Dervis *et al* 1982, Zhuang 1996, Xue 1998, Zheng and Fan 1999, Wu and Xuan 2002, Zhai and Hertel 2005, Willenbockel 2006, He *et al* 2010). In this study, the CET between export and domestic demand equals 4, the Armington elasticity between imported goods and domestic supply equals 2, and the CES between labor and capital lies between 0.1 and 0.7 for the different production sectors. According to benchmark projections, the Chinese economy is assumed to be on a balanced growth path. The emissions are determined from a combination between the economic growth rate and the assumed autonomous pollution efficiency improvements (APEI). APEI numbers are 0.082 for COD, 0.08 for NH_3–N, and 0.079 for other pollutants, which are estimated based on prediction results reported by CAEP and SIC (2008). The PAS elasticities are 0.55 for COD, 0.57 for NH_3–N, and 0.48 for other pollutants, and are assumed to be constant over time, while the existing technical potential to reduce emissions is 0.67 for COD, 0.75 for NH_3–N, and 0.6 for other pollutants. In addition, the assumed APEI are estimated based on prediction results reported by CAEP and SIC (2008).

In China, the depreciation rate was usually 4–7% in the period 1978–2010. In this study, a depreciation rate of 4.5% is determined based on the steady-state relationship between investments and capital. In China, the interest rate on a five-year fixed loan from the Central Bank of China was usually 5.5–8% in the period 2001–10. The interest rate and depreciation rate are calibrated to 8.7% and 4.5%, respectively. Because of the rapid growth of the Chinese economy, the actual lending rate in China is usually higher than the benchmark rate of the Central Bank of China. For practical reasons, a stable annual rate of 8.7% is used.

3. Emission reduction scenarios

In *The Eleventh Five-Year Plan*, a 10% COD reduction target in 2010 is set by central government based on 2005 benchmark data. Furthermore, some local governments set their NH_3–N emission reduction targets. Based on *The Twelfth Five-Year Plan for National Environmental Protection* (SCCG 2011), an 8% reduction target is set by central government for COD and NH_3–N in 2015 based on 2010 benchmark data. Based on *The Twelfth Five-Year Plan for Prevention of Heavy Mental Pollution* (MEP 2011), emission of heavy metal pollutants in the main polluting regions will be reduced by 15% in 2015 based on 2007 benchmark data. In 2007, emission of some pollutants began to decline for the first time, which more or less indicates a return to the emission levels in 2005. *The First National Pollution Census* (MEP, NBS and MOA 2010) was also implemented to provide detailed emission information for the year 2007. Thus we take 2007 rather than 2005 as the benchmark year for our simulations. From this analysis, it is estimated that the emission reduction target for the main pollutants in 2020 will lie between 20 and 30% based on 2007 benchmark data. Therefore, we first set up two alternative

Table 2. The simple version of Chinese ESAM for the year 2007 (unit: 10^8 CNY).

		1	2	3	4	5	6	7	8	9	10	11	12	13	14	Total
Activity	1. Agriculture					48 840										48 840
	2. Industry						577 337									577 337
	3. Service							192 189								192 189
	4. Abatement								611							611
Commodity	5. Agriculture	7 199	26 372	2 796	7							11 478	351	2 101	685	50 990
	6. Industry	10 045	361 153	47 931	216							39 894	0	101 823	82 139	643 202
	7. Service	2 951	54 902	38 645	103							45 882	34 965	7 257	13 311	198 017
	8. Abatement	29	428	37								117	0	0	0	611
Factors	9. Labor	27 140	45 956	36 815	169											110 080
	10. Capital	1 429	61 493	54 507	108											117 537
Institutions	11. Household									110 080	117 537					227 617
	12. Government	48	27 032	11 459	7							24 665				63 210
	13. S-I											105 580	27 894		−22 293	111 181
	14. ROW					2 150	65 864	5 828	0							73 843
	Total	48 840	577 337	192 189	611	50 990	643 202	198 017	611	110 080	117 537	227 617	63 210	111 181	73 843	

Table 3. Equivalences of pollutants included in the OHP emission accounts.

1 kg pollutants =	Pollution equivalents (kg)
Oils	10
Volatile phenol	12.5
Cyanogens	20
Mercury	2000
Cadmium	20
Hexavalent chromium	50
Lead	40
Arsenic	50

emission reduction scenarios with a tradable emission permit system as follows:

(i) S-20%: 20% reduction in emissions needed by the year 2020 in relation to 2007 emission levels;
(ii) S-30%: 30% reduction in emissions needed by the year 2020 in relation to 2007 emission levels.

To compare the costs of environmental policy and investigate the possibility of a higher emission reduction, another two comparative scenarios are set up as follows:

(i) S-40%: 40% reduction in emissions needed by the year 2020 in relation to 2007 emission levels;
(ii) S-50%: 50% reduction in emissions needed by the year 2020 in relation to 2007 emission levels.

The average growth rate of the Chinese economy was about 10% in the period 2005–10, but it is estimated that the growth rate will decline over time in the following decade. Therefore, an 8% growth rate is assumed for the benchmark projection.

4. Policy simulations and key findings

4.1. Macroeconomic results

Changes in the main macroeconomic variables for each simulation scenario are compared with the benchmark projections. Through analyzing the development of gross domestic product (GDP) and GDP growth rate over time, we can gain insights into the economic transition paths induced by the total emission reduction policy. The percentage changes in GDP over time are presented in figure 2. The results indicate that limited emission reduction targets can be met at limited macroeconomic cost, thereby limiting GDP losses for China's economy. The 20–30% emission reduction targets will lead to an accumulated GDP loss in 2020 of 0.29–1.34%. The annual GDP growth rate is projected to reach 7.86–7.98% in 2020, which is very close to the 8% benchmark GDP growth rate (see figure 3). If a total emission reduction of 40–50% is implemented, the estimated GDP loss compared with the benchmark projections is 4.28–8.83% in 2020. With a reduction target of 50% or greater, the GDP growth rate would even be reduced to less than 6% in 2020. These results lead to the important insight that, as the total emission reduction target increases, economic cost increases at a rate faster than linear. On one hand, the producers first select the cheapest options for reducing emissions, and further reductions lead to substantial increases in abatement costs. On the other hand, consumers prefer to keep their original consumption style, which also contributes to raising the cost of economic restructuring. This is especially true if the required emission reduction target is set at a more ambitious level.

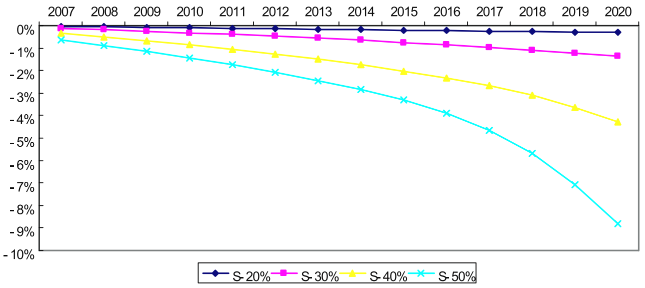

Figure 2. Impact of total emission control policy on GDP (% change compared with benchmark projection).

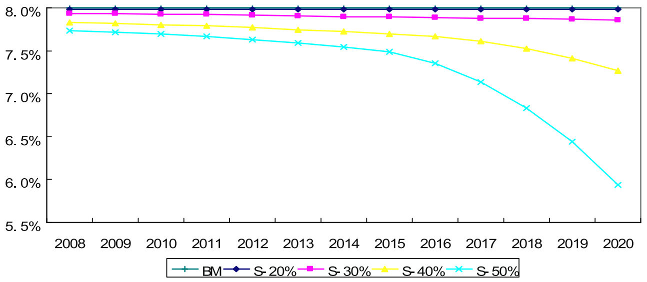

Figure 3. Impact of total emission control policy on growth rate.

In this study, we use the Hicksian equivalent variation (EV) to analyze the impact of water charges on household welfare. Emission reduction targets of 20–30% can lead to a 0.65–2.60% decrease in welfare, while 40–50% emission reduction targets can decrease welfare by 7.41–15.66%. This indicates that the rate at which reductions in household welfare caused by emission reduction targets increase is faster than linear in relation to the stringency of environmental policy. However, we must keep in mind that these welfare losses are induced only by changes in consumption, because the benefits of environmental improvements are not taken into consideration in the household utility function.

To investigate the detailed economic impact of a total emission reduction policy, we use the model to perform a more detailed simulation per cent by per cent, from 20 to 50%. The results show that a modest emission reduction target can almost be achieved at low macroeconomic cost through implementing technical measures and economic restructuring, because marginal abatement costs for small amounts of emission reduction are relatively cheap. When more than a ±30% reduction in emission is implemented, the economic costs and welfare losses would increase substantially. Therefore, policy makers need to balance the considerations of macroeconomic costs and environmental benefits when setting environmental policy targets (see figure 4).

In addition, from figures 2 and 3 we note that GDP and growth rate changes can already be seen in the first year. This is because the private households modeled have perfect foresight in anticipating a stricter environmental policy in future.

Table 4. Sectoral and consumption emissions of COD, NH_3–N and other pollutants to water for China, 2007 (unit: million kilogram).

No.	Sectors	COD	NH_3–N	OHP (PEs)
Y01	Agriculture	13 240.90	1134.00	0.00
Y02	Coal mining and processing	92.14	3.71	6.57
Y03	Petroleum and gas extraction	24.10	1.65	11.12
Y04	Metal ore mining	65.49	1.52	16.27
Y05	Non-ferrous mineral mining	11.76	0.30	0.19
Y06	Food and tobacco processing	1 048.85	43.58	20.20
Y07	Textile apparel	389.05	18.38	2.99
Y08	Clothing products	100.24	10.09	0.70
Y09	Sawmills and furniture	22.94	0.94	0.37
Y10	Paper and printing industry	1 778.96	33.35	4.84
Y11	Petroleum refineries	92.66	11.59	54.95
Y12	Chemical industry	800.51	157.70	43.88
Y13	Nonmetallic mineral products	50.79	3.00	2.30
Y14	Metal smelting and pressing	186.60	19.57	43.97
Y15	Metal products	31.63	1.21	3.47
Y16	Industrial machinery	28.00	2.56	7.37
Y17	Transport equipment	30.42	1.86	7.07
Y18	Electric equipment	11.97	0.58	1.89
Y19	Electronic and telecom equipment	30.00	2.33	1.36
Y20	Instruments and office equipment	7.56	0.42	0.51
Y21	Artwork and other manufacturing	6.11	0.30	0.10
Y22	Scrap and waste	2.31	0.04	0.01
Y23	Electricity	68.43	2.00	5.80
Y24	Gas production and supply	17.34	3.65	4.27
Y25	Water production and supply	17.31	0.87	0.20
Y26	Construction	195.47	19.64	1.59
Y27	Service industry	2344.29	264.63	0.00
	Private households	6363.71	718.37	0.00

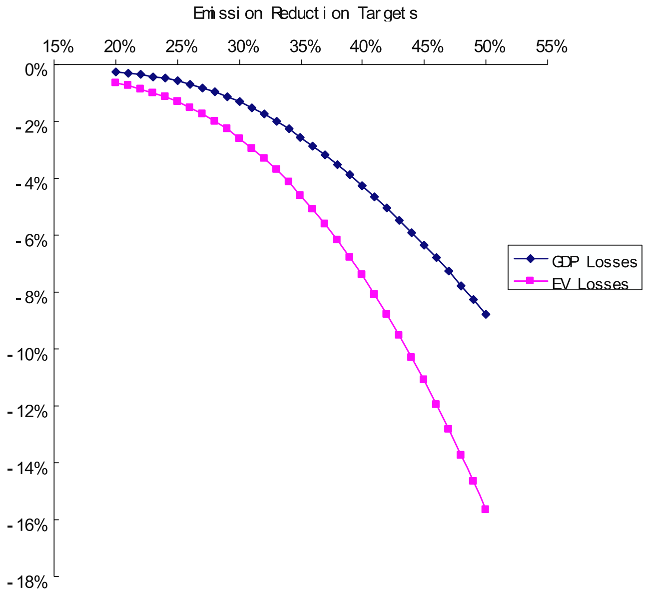

Figure 4. Detailed analysis of economic costs of environmental policy.

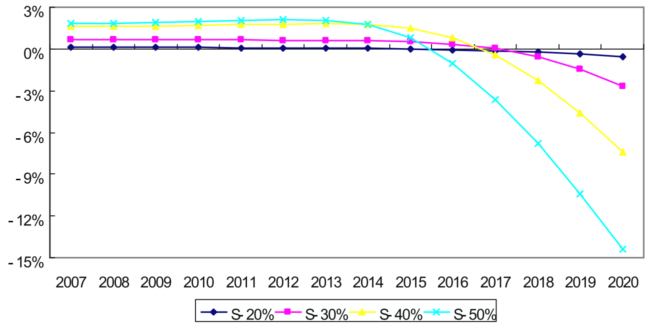

Figure 5. Impact of total emission control policy on total consumption of private households (% change compared with benchmark projection).

Increasing production costs caused by environmental policy will lead to rising commodity and service prices. Consumers also need to increase their expenditure on abatement services for their domestic water use. To reduce their welfare losses, they would spend more on current consumption, the cost being lower consumption levels in later years. Figure 5 shows that 20–50% emission reduction targets can result in a 0.16–1.82% increase in consumption levels of private households in the first year, whereas their consumption levels in the year 2020 are 0.58–14.35% lower than the benchmark projection. The results indicate that if environmental policy becomes stricter, private households would increase their consumption substantially in the short term rather than save, because this has a positive effect on household welfare. However, lower savings will translate into lower investments in the long term (see figure 6). Lower investment levels will in turn lead to a lower rate of economic growth, and consumption, production and income are all well below the long-term benchmark projections.

4.2. Sectoral results

The multi-sectoral structure of the environmental CGE model used in this study enables a detailed analysis to be made of the

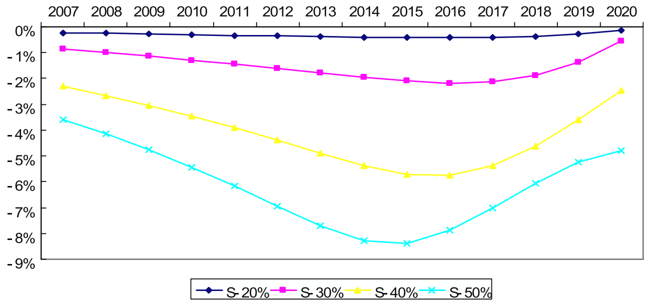

Figure 6. Impact of total emission control policy on investment (% change compared with benchmark projection).

impact on different sectors in the economy. Because different sectors have different emission intensities and abatement costs, the implementation of a total emission reduction policy will lead to diverse impacts on production, consumption and trade in different sectors.

Figure 7 shows the impact of total emission reduction targets on sectoral production in 2020. Compared with the benchmark projections, the impact of environmental policy on production differs substantially between sectors. While the implementation of a total emission reduction policy can lead to increases in production costs for all sectors, this does not mean that all production sectors will be negatively affected by the policy. Some production sectors with high emission intensities and abatement costs are severely affected, whereas other sectors that provide relatively clean goods and services can actually benefit from stricter environmental targets. From figure 7, we see that the sectors with substantial reductions in production are the sectors agriculture, food and tobacco processing, textile apparel, clothing, sawmills and furniture, paper and printing industry, chemical industry, artwork and other manufacturing. At the same time, the environmental policies being discussed create opportunities for other production sectors, such as metal smelting and pressing, metal products, industrial machinery, and electric equipment, and especially the electronic and telecom equipment sector. Stricter total emission reduction targets increase production values in these sectors, and consequently total emission reduction policies may lead to an important shift in emphasis from dirty sectors to relatively clean sectors. Sectoral results indicate that the implementation of environmental policy can result in a reallocation of resources (labor and capital) and not just an economic decline.

To reduce the negative impacts on welfare, private consumers increase consumption levels initially but reduce

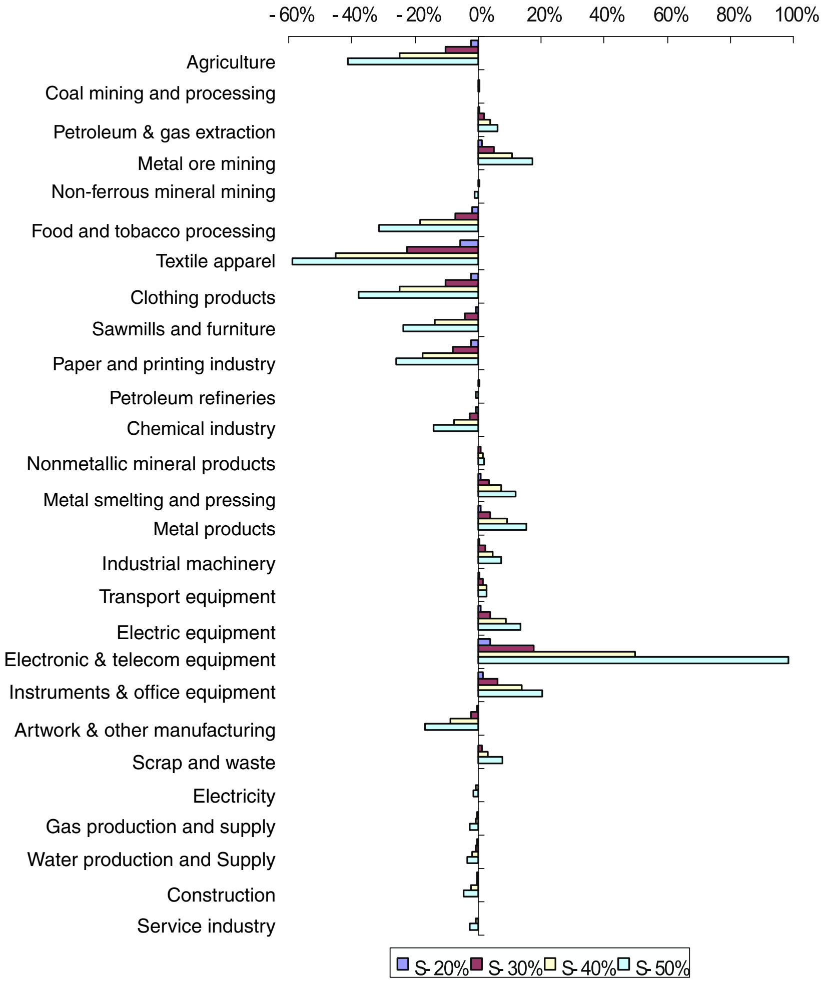

Figure 7. Impacts of the total emission control targets on sectoral production in 2020 (% change compared with benchmark projection).

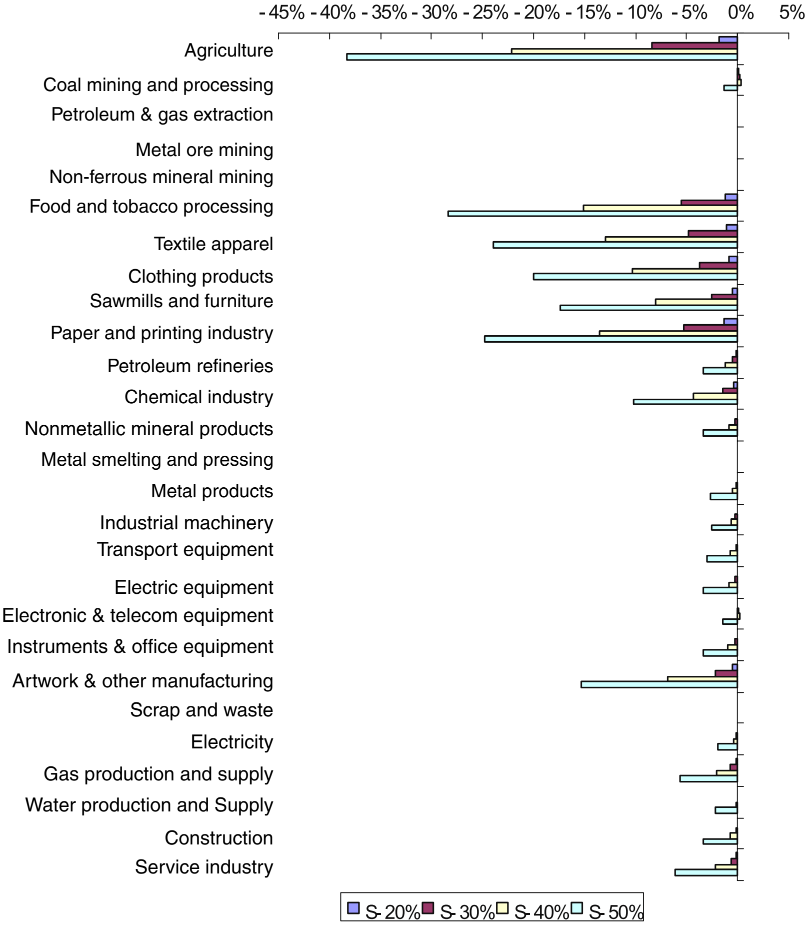

Figure 8. Impacts of the total emission control targets on consumption of private households in 2020 (% change compared with benchmark projection).

their consumption in the long run. However, the impacts of consumption caused by the total emission control policy differ across sectors, because environmental policy has different impacts on production costs in different sectors owing to their differing emission intensities and abatement costs. Figure 8 shows that in 2020 there is a substantial reduction in demand from private households for products provided by the agriculture, food and tobacco processing, textile, clothing, sawmills and furniture, paper and printing, chemical, and artwork and other manufacturing sectors. This is because strict total emission reduction targets raise the prices of these products more than those of other products, and hence it is beneficial for private households to substantially reduce their consumption demand on these sectors.

Based on the Heckscher–Ohlin (HO) theorem (Heckscher 1919, Ohlin 1933) for international trade, the comparative advantage of different countries is dependent on their relative factor endowments. The implementation of a total emission control policy will also change the international competitiveness of China. On one hand, environmental policy has a different impact on the production cost of different sectors because of their different emission intensities and/or abatement costs; on the other hand, the reallocation of resources (labor and capital) endowments induced by policy targets also has a different effect on the comparative advantage of international trade of different sectors. Sectors with high emission intensities and/or abatement costs will see their comparative advantage of international trade reduced, and their exports will decline substantially in line with the stringency of a total emission reduction policy, whereas other sectors that provide relatively clean goods and services can even benefit from stricter environmental targets and achieve opportunities to increase exports of their products (see figure 9). The sectors with a substantial reduction in their production levels will increase their imports from other countries in order to satisfy domestic supply (see figure 10). Most of these sectors have relatively high emission intensities or abatement costs, or are indirectly affected by related sectors. Thus a total emission reduction policy can effect a shift in the trade structure of China's economy and significantly reduce domestic emissions at a relatively small macroeconomic cost.

From the analysis of sectoral results, we also found that some clean sectors have a substantial increase in production and exports. For example, exports of electronic and telecom equipment increase substantially when the reduction target is very high, with a 40 or 50% emission reduction. This is because the electronic and telecom equipment sector, which is an internationally competitive sector in China, exports the majority of its products to the world market. In addition, because of its relatively low abatement cost, the input resources

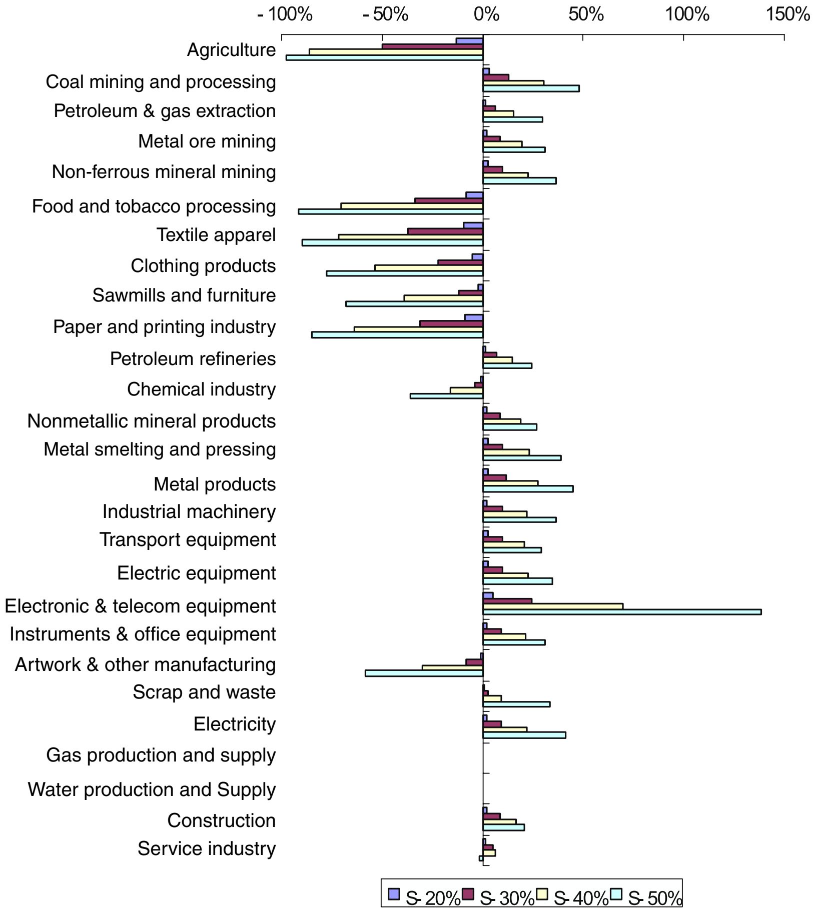

Figure 9. Impacts of the total emission control targets on exports in 2020 (% change compared with benchmark projection).

released by the polluting sectors are reallocated to the sector. Therefore, this stimulates the substantial increase in its production and exports. However, we must keep in mind that the reallocation of input resources is not free. Especially when the reduction target is very high, aiming at a 40 or 50% emission reduction, reallocating input resources becomes more and more expensive. For example, in this model there is only one labor category and labor is assumed to fully mobile between sectors. Actually mobilization of labor from low-technical sectors to a relatively high-technical sector usually requires a lot of training. Therefore, changes in the production, consumption and trade in some sectors need to be carefully investigated.

4.3. Abatement and environmental results

The tradable permit prices for emissions in table 5 are given as the price of 1 kg of emissions for COD and NH_3–N, and 1 kg of PEs for other pollutants. The rate of increase in permit prices over time is faster than linear when total emission reduction targets are implemented gradually in China's rapidly growing economy. There is also an above-linear increase in the price of permits in relation to the stringency of environmental policy.

When emission permits become more expensive, the demand for abatement efforts increases, calling for higher environmental expenditure. As a result, abatement sectors will benefit from a strict environmental policy and will develop rapidly. Figure 11 shows the development of abatement services over time, assuming a 30% reduction in total emissions for each pollutant. Under this reduction target, the demand for abatement services would increase 8.4 times for COD, 6.0 times for NH_3–N, and 3.0 times for other pollutants by 2020, whereas in the same period total output would increase only by a factor of 2.7. The results also show that the changes in demand for abatement services by production sectors differ for each specific pollutant. It means we must disaggregate the abatement sector into a multi-sectoral abatement structure that allows us to capture more detailed changes in abatement service demand for specific pollutants.

Another important point we must keep in mind is that the impact of environmental policy on production sectors can be induced not only directly by high emission intensities and abatement costs, but also indirectly through increased production costs in related sectors that provide production inputs (Qin *et al* 2011). For example, the production of the textile sector is substantially reduced (see figure 7), whereas the increase in its abatement cost is lower than the average level (see table 6). The reason for this is that agricultural products are the main production inputs for the textile industry, and so the effects of the environmental policy on the agriculture sector indirectly impact production levels in the textile sector.

From table 6 we can see that in sectors with relatively high emission intensity or a marginal abatement cost for one

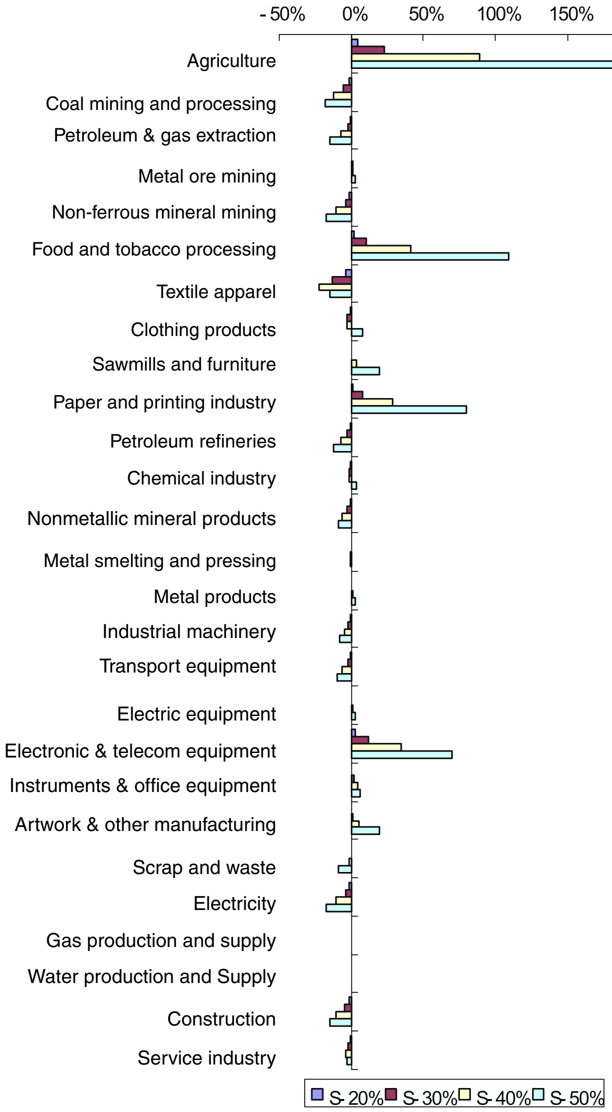

Figure 10. Impacts of the total emission control targets on imports in 2020 (% change compared to benchmark projection).

Table 5. Prices of tradable emission permits (CNY kg^{-1} in constant 2007 prices).

	S-20% reductions			S-30% reductions			S-40% reductions			S-50% reductions		
Year	COD	NH_3–N	OHP	COD	NH_3–N	OHP	COD	NH_3–N	OHP	COD	NH_3–N	OHP
2007	0.7	0.875	0.7	0.7	0.875	0.7	0.7	0.875	0.7	0.7	0.875	0.7
2008	1.00	1.24	0.96	1.00	1.24	0.96	1.01	1.24	0.96	1.01	1.24	0.95
2009	1.47	1.79	1.34	1.48	1.80	1.33	1.48	1.81	1.32	1.49	1.81	1.31
2010	2.24	2.68	1.88	2.25	2.69	1.87	2.27	2.71	1.84	2.29	2.73	1.81
2011	2.88	3.45	2.34	3.17	3.75	2.45	3.53	4.13	2.54	3.95	4.55	2.64
2012	3.74	4.49	2.92	4.57	5.36	3.24	5.78	6.57	3.54	7.45	8.17	3.91
2013	4.89	5.89	3.65	6.80	7.87	4.30	10.1	11.1	5.01	16.0	16.2	5.91
2014	6.48	7.83	4.56	10.5	11.9	5.74	19.3	20.0	7.17	39.9	36.0	9.19
2015	8.69	10.5	5.72	16.9	18.9	7.71	40.4	39.1	10.4	105	83.0	14.7
2016	11.8	14.4	7.18	28.6	31.2	10.4	88.3	79.4	15.4	239	178	24.5
2017	16.3	20.1	9.03	50.4	53.7	14.3	181	157	23.3	458	357	43.2
2018	22.9	28.4	11.4	90.3	95.2	19.6	328	298	36.2	774	704	83.0
2019	32.6	41.2	14.4	157	169	27.3	538	554	58.4	1197	1422	186
2020	47.1	60.9	18.3	257	295	38.6	812	1035	99.4	1712	3043	570

pollutant, demand for abatement services for that pollutant will increase more than in other sectors. If emission permits are not allowed to be traded, the polluters will have to reduce their emission levels via abatement measures or reduce their production levels. If tradable emission permit schemes are implemented, sectors with high emission intensity or marginal

Table 6. Changes in demand for abatement services and sectoral emissions in 2020 with a 30% emission reduction in China (benchmark index = 1).

	Abatement services				Emissions		
Sectors	COD	NH_3–N	OHP	Total	COD	NH_3–N	OHP
Agriculture	16.0	16.7	N/A	16.1	0.83	0.82	N/A
Coal mining and processing	5.2	6.6	3.3	5.1	0.50	0.49	0.71
Petroleum and gas extraction	4.2	4.4	3.0	3.2	0.47	0.41	0.68
Metal ore mining	4.4	14.2	3.2	3.9	0.49	0.77	0.71
Non-ferrous mineral mining	5.0	15.8	2.9	4.7	0.50	0.81	0.68
Food and tobacco processing	7.4	3.6	4.4	6.3	0.55	0.36	0.78
Textile apparel	4.5	2.7	2.3	3.8	0.41	0.29	0.52
Clothing products	5.0	5.0	2.6	4.7	0.46	0.40	0.60
Sawmills and furniture	7.6	8.7	2.9	7.0	0.57	0.55	0.65
Paper and printing industry	8.1	5.7	2.8	7.8	0.57	0.43	0.63
Petroleum refineries	6.5	3.4	3.0	3.5	0.54	0.37	0.68
Chemical industry	6.2	4.7	2.9	4.9	0.53	0.41	0.66
Nonmetallic mineral products	5.5	4.6	3.0	4.7	0.51	0.42	0.68
Metal smelting and pressing	7.3	3.6	3.0	3.5	0.58	0.39	0.69
Metal products	6.6	6.7	3.0	3.3	0.56	0.50	0.70
Industrial machinery	5.9	6.8	3.2	4.8	0.53	0.50	0.71
Transport equipment	5.0	4.2	3.1	4.1	0.50	0.40	0.69
Electric equipment	4.3	4.2	3.1	4.0	0.49	0.41	0.71
Electronic and telecom equipment	4.2	4.5	3.4	3.9	0.53	0.45	0.79
Instruments and office equipment	4.3	3.3	3.1	3.6	0.49	0.38	0.71
Artwork and other manufacturing	7.9	10.0	2.8	4.7	0.58	0.60	0.65
Scrap and waste	7.3	N/A	2.9	5.2	0.57	N/A	0.68
Electricity	3.9	4.0	3.1	3.8	0.46	0.39	0.69
Gas production and supply	11.1	7.3	3.5	7.0	0.69	0.51	0.72
Water production and supply	6.7	3.9	2.9	5.0	0.55	0.39	0.67
Construction	12.4	9.3	2.9	8.6	0.74	0.58	0.67
Average of industry	6.2	4.0	3.0	4.7	0.55	0.41	0.70
Service industry	10.9	12.6	N/A	11.0	0.69	0.70	N/A
Private households	9.9	11.5	N/A	10.0	0.65	0.65	N/A
Total	8.4	6.0	3.0	6.6	0.70	0.70	0.70

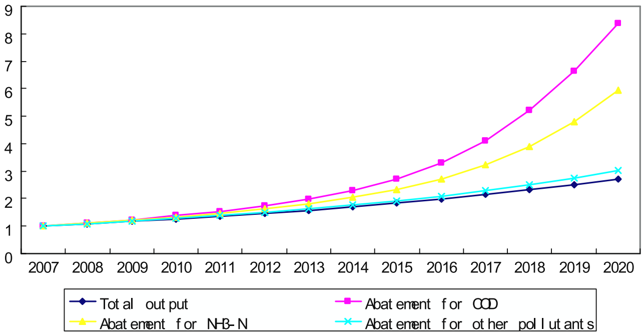

Figure 11. Developments in abatement services over time with a 30% reduction of total emission permits in China (benchmark index = 1).

abatement cost for one pollutant can buy more emission permits for that pollutant to reduce their expenditure for abatement services.

A tradable emission permit system has a positive impact on production levels, avoiding the macroeconomic cost caused by non-tradable permits. To certify the positive impact of tradable emission permits, a second version of the model with a non-tradable emission permit system is also developed. In this version, all producers and consumers are required by the government to reduce their emission levels proportionately. Table 7 presents the comparative results for the main macroeconomic variables. Comparative analysis indicates that an emission trade policy can reduce the negative impacts of policy change on GDP, growth rate, NNI and welfare.

Table 7. Macroeconomic results of tradable and non-tradable permits in 2020.

	Tradable permits		Non-tradable permits	
Scenarios (unit: per cent)	20% reduction	30% reduction	20% reduction	30% reduction
GDP	−0.29	−1.34	−1.11	−2.46
Growth rate	7.98	7.86	7.94	7.62
NNI	−0.32	−1.49	−1.11	−2.58
EV	−0.65	−2.60	−1.47	−3.86

4.4. Sensitivity analysis

In order to investigate the robustness of the model, we carried out a brief sensitivity analysis on the crucial parameters that are directly related to the newly introduced pollution/abatement mechanism. Table 8 presents the results for the base specification and for the alternative values of the PAS elasticity, technical potential and APEI for the 30% reduction scenarios.

As a key parameter in the model, the PAS elasticity is increased or decreased by 0.05 for one pollutant a time.

Table 8. GDP and EV losses in the 30% reduction scenario for alternative values of main parameters.

	GDP losses in 2020				EV losses			
Parameter change	Base	COD	NH$_3$ N	OHP	Base	COD	NH$_3$ N	OHP
PAS elas. + 0.05	−1.34	−1.14	−1.31	−1.34	−2.60	−2.32	−2.55	−2.59
PAS elas. − 0.05	−1.34	−1.58	−1.43	−1.34	−2.60	−2.93	−2.81	−2.60
Tech. potential + 0.05	−1.34	−1.23	−1.33	−1.34	−2.60	−2.39	−2.57	−2.59
Tech. potential − 0.05	−1.34	−1.46	−1.36	−1.34	−2.60	−2.84	−2.64	−2.60
APEI + 0.003	−1.34	−0.92	−1.31	−1.34	−2.60	−1.96	−2.54	−2.59
APEI − 0.003	−1.34	−1.92	−1.43	−1.34	−2.60	−3.48	−2.83	−2.60

The results of the sensitivity analysis indicate that the higher the PAS elasticity, the lower the GDP losses and EV losses. This is because the higher elasticity implies better substitution possibilities between buying emission permits and adopting abatement measures. The PAS elasticity for COD shows the largest impact on GDP and EV, but for other pollutants the elasticity has a very minor impact on the economic costs of the total emission control policy.

In the sensitivity analysis, the technical potential for emission reduction is increased and decreased by 0.05 for one pollutant at a time. Compared with other parameters, changes in technical potential have a relatively smaller impact on the results. The results of the sensitivity analysis indicate that a higher technical potential will reduce the economic costs of emission reduction policy. The largest impact on GDP and EV is also caused by the technical potential change for COD.

Another key parameter of the model is APEI. Therefore, APEI is increased or decreased by 0.003 for one pollutant at a time in the sensitivity analysis. The results of the sensitivity analysis indicate that changes in APEI values for COD influence GDP and EV substantially. Increasing the APEI for COD will substantially reduce the costs of environmental policy, and COD is the dominant pollutant in the total emission control policy.

5. Conclusion

This study examines the effectiveness of a total emission control policy in China and, using an extended environmental dynamic CGE model, assesses the economic impacts of implementing 20–50% total emission reduction targets by 2020. We made a multi-abatement-sector extension to the model, which captures more detailed dynamic interactions between the costs of abatement and the price of emission permits.

The results indicate that a modest total emission reduction target can be achieved at a low macroeconomic cost. With the stringency of policy targets, the macroeconomic cost (for example, GDP loss and welfare loss) will rise at an increasing rate. However, growth rates might decline over time, and the pressure of increasing pollution might also decline over time. In addition to continual technical improvements, we conclude that in the future emission abatement will be possible at a lower macroeconomic cost. Therefore, the current environmental policy is appreciated in China.

A stringent environmental policy can lead to an important shift in production, consumption and trade patterns from dirty sectors to cleaner sectors, because the implementation of the environmental policy can result in a reallocation of resources in China's economy rather than just a decrease in economic growth.

Results from our simulations indicate that with a total emission reduction policy in China, tradable emission permits can reduce the macroeconomic cost and negative impacts on welfare through reducing the average cost of abatement services. Therefore, local governments should be encouraged to permit the trading of emission permits, and a tradable emission permit system for more pollutants should be developed throughout the country.

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