WEP issue 01-96, 15 May 1996

Wageningen Economic Papers

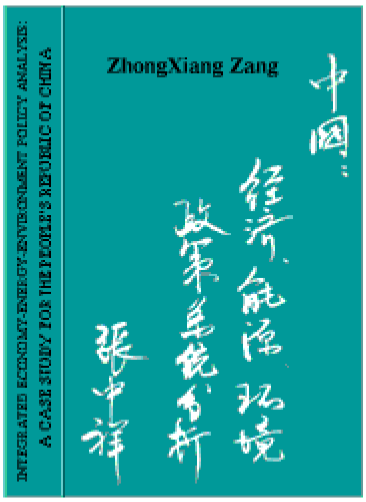
Macroeconomic Effects of CO2 Emission Limits: A Computable General Equilibrium Analysis for China

About the author

ZhongXiang Zhang was born in Yuncheng of the Shanxi Province in the People's Republic of China on December 27 1963. After graduation from the Postgraduate School of the Tianjin University (the oldest Chinese University) in 1987 with an MSc in Energy Engineering, he immediately started working at the Economic Research Centre of the State Planning Commission in the People's Republic of China.

From July 1989 till September 1990, he worked at the Faculty of Business Administration of the University of Twente in the Netherlands and at the Policy Studies Department of the Netherlands Energy Research Foundation in Petten. Since October 1990 he has been a research fellow at the Department of General Economics of the Landbouwuniversiteit (Wageningen Agricultural University WAU) in Wageningen the Netherlands. He received his PhD on april 10 1996 on his thesis Integrated economy-energy-environment policy analasis: a case study for the Peoples republic of China.

Over the past nine years he has been working on a variety of projects funded by a variety of Chinese and international institutions. He has published many papers in the area of environmental economics and plicies, energy economics and policies, energy systems analysis, economic modelling, and development economics. He is a member of the New York Academy of Sciences.



He has founded the Interdisciplinary Research Association of the Tianjin University and served as a member of the Youth Committee of the State Planning Commission. Het has taken part in the reception of many Chinese official delegations to Holland and has been co-organising the Chinese-Dutch workshop on Economic Development, Resource Management and Environmental Protection in Beijing, april 22-26 1996.

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(*) For presentations at the 7th Global Warming International Conference, Vienna, April 1-3, 1996; the Chinese - Dutch Workshop on Economic Development, Resource Management and Environmental Protection, Beijing, April 22-26, 1996; and at the Seventh Annual Conference of the European Association of Environmental and Resource Economists, Lisbon, June 27-29, 1996. It is based on Chapter 7 of Zhang (1996).

Abstract

The paper analyzes the macroeconomic effects of limiting China's CO2 emissions by using a time-recursive dynamic computable general equilibrium (CGE) model of the Chinese economy. The baseline scenario for the Chinese economy over the period to 2010 is first developed under a set of assumptions about the exogenous variables. Next, we analyze the macroeconomic implications of two less restrictive scenarios under which China's CO2 emissions in 2010 will be cut by 20% and 30% respectively relative to the baseline, assuming that carbon tax revenues are retained by the government. Then, we compute the efficiency improvement of four indirect tax offset scenarios relative to the two tax retention scenarios above. Furthermore, a comparison with other studies for China, which include the well-known global studies based on GLOBAL 2100 and GREEN, is made in terms of both the baseline scenarios and carbon constraint ones. The paper ends with some concluding remarks.

Key words:

carbon dioxide emissions, carbon tax, China, computable general equilibrium model, energy consumption, GLOBAL 2100, GREEN, macroeconomic effects.

Acknowledgements

The author would like to thank the Netherlands National Research Programme on Global Air Pollution and Climate Change for financial support, Henk Folmer for supervision during the course of the research, and Ekko van Ierland for helpful comments on an earlier version of this paper. The usual caveat applies.

1 Introduction

At present China, as the world most populous country and largest coal producer and consumer, alone contributes 11% of global CO2 emissions (Manne and Richels, 1991a). This means that China ranks second in global CO2 emissions if the Soviet emissions are distributed over the new independent republics. Under a business-as-usual scenario, China's contribution to global CO2 emissions is estimated to rise to 17% in 2050 and to 28% in 2100 (Manne, 1992). Thus, advocates of controlling CO2 emissions call for substantial efforts in China.

However, the Chinese authorities have argued that China cannot be expected to make a significant contribution to the carbon emission problem unless China receives very large international aid for this purpose. This contrasts sharply with the wishes of proponents of controlling CO2 emissions. This paper is devoted to explaining this difference in opinion by analysing the economic implications of possible future CO2 emissions limits in China through a newly-developed time-recursive dynamic computable general equilibrium (CGE) model of the

Chinese economy. We believe that such an analysis is also useful to broaden the picture painted by global models, thus serving as a complement of the results obtained through global models.

The remainder of the paper proceeds as follows. Section 2 describes briefly main features of the CGE model for China. In Section 3 the business-as-usual scenario is developed assuming no specific policy intervention to limit the growth rate of CO2 emissions. In Section 4, counterfactual policy simulations are carried out to compute the macroeconomic implications of two alternative carbon limits relative to the business-as-usual scenario, assuming that the carbon tax revenues are retained by the government. In Section 5, four carbon tax revenue recycling scenarios are constructed to illustrate the efficiency improvement from offsetting carbon tax revenues with reductions in indirect taxes relative to the carbon tax revenue retention scenarios above. A comparison with other studies for China in terms of both the baseline scenarios and the carbon constraint ones is presented in Section 6. The paper ends with some concluding remarks.

2 Main features of the CGE model for China (1)

In analysing the economic impacts of limiting CO2 emissions, Zhang and Folmer (1995c) and Zhang (1996) have argued that a CGE approach is generally considered an appropriate tool. Thus, a time-recursive dynamic CGE model of the Chinese economy (2) has been developed for such a purpose.

The CGE model of the Chinese economy operates by simulating the operation of markets for factors, products and foreign exchange. It is highly non-linear, with equations specifying supply and demand behaviour across all markets. Moreover, with focus being placed on addressing such energy and environmental issues as quantifying the economy-wide effects of policies aimed at limiting CO2 emissions, our model pays particular attention to modelling the energy sector and its linkages to the rest of the economy, because the CO2 emissions from fossil fuel combustion in the energy system is the main source of man-made CO2 emissions, which in turn are the major cause of the greenhouse effect. This makes our CGE model different from other CGE models for China in several aspects. (3)

Our model includes ten producing sectors and is made up of the following blocks: production and factors, prices, income, expenditures, investment and capital accumulation, foreign trade, energy and environment, welfare, and market clearing conditions and macroeconomic balances. In our CGE model, energy use is disaggregated into coal, oil, natural gas and electricity. Along with capital, labour and intermediate inputs, the four energy inputs are regarded as the basic inputs into the nested constant elasticity of substitution-Leontief production function (see Figure 1). Moreover, our model incorporates an explicit time dimension, and has a transparent representation of the rate of autonomous energy efficiency improvement (AEEI) unrelated to energy price increases if dynamic linkages proceed. So, the effect of the AEEI parameter can easily be assessed.

Thus, our CGE model, which is also rich in treatment of foreign trade and is appropriate for modelling the household consumption, allows endogenous substitution among energy inputs and alternative allocation of resources as well as endogenous determination of foreign trade and household consumption in the Chinese economy in order to cope with environmental restrictions, at both sectoral and macroeconomic levels. The equilibrium solution to the model for a given year produces a wealth of detailed information, including market clearing prices, GNP, productivity levels by industry, investment by industry, final consumption levels by commodity, employment by industry, imports and exports by commodity, fuel-specific production in physical terms, energy consumption patterns, and CO2 emissions.

Moreover, the Hicksian equivalent variation is calculated to measure the welfare impacts of, say, emission abatement policies. Furthermore, the CGE model incorporates an explicit tax system. This makes it suitable for estimating the `double dividend' from the imposition of a carbon tax that is incorporated as a cost-effective means of limiting CO_2 emissions. (4) Finally, the model is solved directly with a numerical solution technique included in GAMS.

The CGE model for China has been calibrated using 1987 data, which have been aggregated into three broad categories: a) detailed economic accounts, which are ideally maintained in the form of a Social Accounting Matrix (SAM); b) structural parameters; and c) a number of subsidiary data. (5)

Notes

(1) See Chapter 5 of Zhang (1996) for a detailed description of the CGE model for China.
(2) Recursive dynamic CGE models mean that a time sequence of single-period equilibria is computed for periods $t = 1, 2,...$. Periods are related through the updating of some exogenous variables such as capital stock or demography (Gunning and Keyzer, 1995).
(3) See Zhang (1996) for a brief description of other CGE models for China.
(4) A carbon tax is more cost-effective in terms of target achievement than an energy tax. Moreover, compared with an energy tax, a carbon tax is less burdensome in that it raises a smaller amount of government revenues for a given reduction of CO_2 emissions (Zhang, 1996). This has clearly been shown in the empirical studies of Jorgenson and Wilcoxen (1993b) and Beauséjour *et al.* (1995).
(5) See Chapter 6 of Zhang (1996) for a detailed discussion of constructing the 10-sector version of 1987 SAM for China and the calibration procedure.

3 The business-as-usual scenario

Before turning to macroeconomic analysis of CO_2 limits, we first have to develop the business-as-usual (BaU) scenario for economic development, energy consumption and CO_2 emissions in China, because any assessment of economic impacts of limiting CO_2 emissions starts with establishing a plausible baseline path. This BaU scenario assumes no policy intervention to limit the rate of CO_2 emissions, but does allow for anticipated changes in demographic, economic, industrial and technological developments and environmental policies not directly aimed at CO_2 emission reduction.

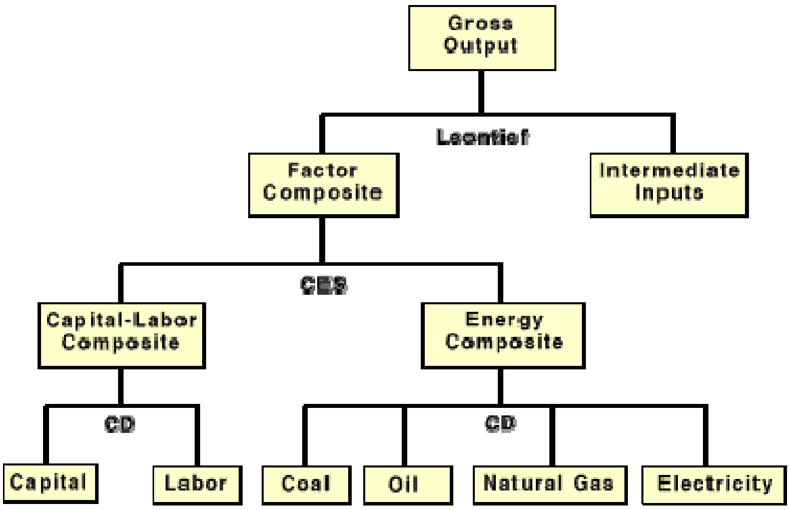

Figure 1 Nesting structure of production in the CGE model

Develop the BaU scenario by using the time-recursive dynamic CGE model involves two steps. The first step is making a set of underlying baseline assumptions about how the exogenous variables in the model would evolve over the period till 2010. This involves updating time-dependent variables and revising certain parameters over time to reflect worldwide economic development and changes in tastes or technology. The second step is using these assumptions to construct the BaU projections about the endogenous variables.

Table 1 summarizes the main macroeconomic results of the baseline simulation. (6) The baseline scenario is characterized by a rapid economic growth. As shown in Table 1, GNP is expected to grow at an average annual rate of 8.34% for the period from 1990 to 2000 and 7.55% thereafter to 2010. Although the calculated rates of GNP growth are lower than those achieved in the early 1980s and 1990s, they are well in line with the government targets of GNP growth rate, which are set at 8-9% per annum for the period 1990 - 2000 and at 7.2% thereafter to 2010. (7)

Given that growth of the labour force is very small and declining significantly during the second period, which means that its contribution to output growth is also small in absolute terms and declining significantly in relative terms, such rapid economic growth is attributed partly to the increased factor productivity and mainly to increased capital stock. This reflects the long-established policy of the Chinese policymakers to rely on capital accumulation as the primary source of economic growth. But growth of capital depends on investment. Moreover, the existing bottlenecks in some sectors of capital-intensive nature (e.g. energy and transport), and, more generally, imbalances in the output structure require adjustment in the capital structure. Consequently, investment is expected to grow at a faster rate than GNP, as shown in Table 1. As can also be seen, the increasing exports form one of the driving forces behind China's booming economy.

Table 1 Main macroeconomic results for the baseline scenario
(average annual growth rates)

Volumes	**2000/1987**	**2010/2000**
GNP (%)	7.92 **(a)**	7.55
Private consumption (%)	6.48	6.54
Investment (%)	8.81	7.81
Exports (%)	8.95	8.11
Imports (%)	6.86	5.12
Gross output (%)	8.25	7.86

(a) Converted to the period 1990 - 2000, this figure is equivalent to 8.34%, indicating the slowdown of economic growth during a period of economic retrenchment from 1988 to 1990.

Table 2 shows the energy-related results for the baseline scenario. Rapid economic growth will lead to increased energy consumption and hence CO2 emissions, notwithstanding the reduced energy intensity of GNP.

As shown in Table 2, total energy consumption is expected to rise from 987.0 Mtce (Million tons of coal equivalent) in 1990 to 1546.4 Mtce in 2000 and to 2560.4 Mtce in 2010. Consequently, the baseline CO2 emissions are expected to grow from 586.9 MtC (Million tons of Carbon) in

1990 to 898.9 MtC in 2000 and to 1441.3 MtC in 2010 at an average annual rate of 4.4% for the period to 2000 and 4.8% thereafter to 2010. The slightly accelerated growth of CO2 emissions during the second period is partly because economic growth, although somewhat slow in this period, still remains strong, and partly because of the reduced energy conservation rate as well as no significant change in the coal-dominated pattern of energy consumption. On a per capita basis, China's energy consumption of 0.86 tce in 1990 is expected to rise to 1.19 tce in 2000 and to 1.80 tce in 2010, while the corresponding CO2 emissions of 0.5 tC in 1990 are expected to rise to 0.7 tC in 2000 and to 1.0 tC in 2010. Although the figures are doubled over twenty years, they are still well below the corresponding current world average levels, which were equal to 2.12 tce and 1.14 tC respectively in 1990. (8)

It should be emphasized that although the rapid growth of energy consumption and hence CO2 emission per capita is attributed largely to rapid economic growth, it is attributed partly to the low population growth due to the implementation of a strict family planning policy.

Table 2 Energy-related results for the baseline scenario

	1990	**2000**	**2010**
Energy consumption (Mtce)	987.0	1546.4	2560.4
Energy consumption per capita(tce)	0.86	1.19	1.80
Coal (Mt)	1055.2	1578.9	2418.2
Coal's share in total energy consumption (%)	76.2	72.9	67.5
Electricity (TWh)	623.0	1395.7	2745.2
Energy intensity of GNP (kgce/yuan)	0.717	0.504	0.403
Elasticity of energy consumption w.r.t. GNP **(a,b)**>	0.56	0.55	0.68
Elasticity of electricity consumption w.r.t. GNP **(a,b)**	0.84	1.01	0.93
Average annual rate of energy conservation (%) **(b)**	3.6	3.46	2.21
CO2 emissions (MtC)	586.9	898.9	1441.3
CO2 emissions per capita (tC)	0.51	0.69	1.01

(a) w.r.t. is short for with respect to.
(b) The figures in 1990 are for the period 1980 - 1990, in 2000 for the period 1990 - 2000, and in 2010 for the period 2000 - 2010.

Notes

(6) Because CGE models for resource allocation are unable to determine the absolute price level, it is meaningless to discuss a variety of price indexes under the baseline scenario, although their percentage deviations as a result of the imposition of a carbon tax relative to the baseline are important (see the next section). Thus, we only report changes in the underlying volumes.

(7) The recent Chinese Communist Party Central Committee's Proposals for National Economic and Social Development during the Ninth Five-Year Plan Period and up to the year 2010 set the goal of doubling China's 2000 GNP by the year 2010, although in principle it is subject to formal approval by the National People's Congress (the Chinese Parliament) in March 1996 (People's Daily (Overseas Edition), 29 September 1995).
(8) The world average levels of energy consumption and CO_2 emissions have been calculated based on data from Dean and Hoeller (1992) and British Petroleum (1993).

4 Carbon abatement: counterfactual policy simulations

In this study six scenarios are considered.(9) First two scenarios as shown in Figure 2 are specified in terms of reductions in CO_2 emissions relative to the BaU path (10) as follows:

Scenario 1: 20% cut in CO_2 emissions in 2000 and 2010 respectively;
Scenario 2: 30% cut in CO_2 emissions in 2000 and 2010 respectively.

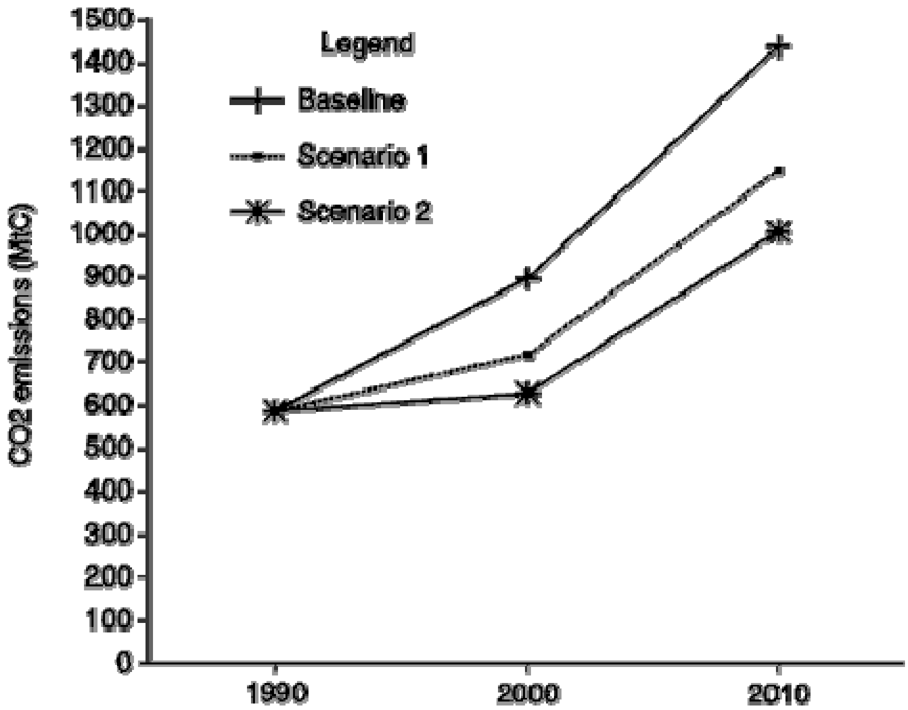

Figure 2 CO_2 emissions in China under alternative scenarios

In the two simulations the carbon tax revenues are retained by the government. Zhang and Folmer (1995a) and Zhang (1996) have argued that using the revenues raised to reduce a distortionary tax would lower the net adverse effects of carbon taxes by reducing inefficiency elsewhere in the economy and that the macroeconomic effects of offsetting carbon tax revenues with reductions in indirect taxes are more positive than in other tax offset cases. Thus, this will probably be the most likely use of the revenues. To determine how large the efficiency improvement might be, four tax reform simulations are constructed as follows:

Reforms 1a and 1b maintain the carbon tax of Scenario 1, but indirect tax rates for all sectors are equally reduced by 5% and 10% respectively.

Similarly, Reforms 2a and 2b maintain the carbon tax of Scenario 2, but indirect tax rates for all sectors are equally reduced by 5% and 10% respectively.

Such counterfactual simulations as shown in Table 3 allow us to compute the implications of two alternative carbon limits relative to the business-as-usual scenario, and the efficiency improvement of four indirect tax offset scenarios relative to the tax retention scenarios. In this section we focus on discussing the first two simulations, while reporting the results from the four tax reform simulations will be the subject of Section 5.

Table 3 Six policy simulations considered in this study

Scenario	Changes in CO2 emissions relative to the baseline	Changes in indirect tax rates relative to the baseline
Scenario 1	-20%	no change
Reform 1a	-20%	-5%
Reform 1b	-20%	-10%
Scenario 2	-30%	no change
Reform 2a	-30%	-5%
Reform 2b	-30%	-10%

Notes

(9) The number of scenarios that can be developed with this CGE model is infinite. Given time constraints, however, only six scenarios are developed in the present study.
(10) Note that we use the BaU solution as the reference with which all alternative scenario solutions are compared, rather than the level of emissions in a single base year. The latter would be a much more restrictive target. It could be defended for industrialized countries which already enjoy a high level of output and consumption. It is also of policy relevance for industrialized countries because the Framework Convention on Climate Change commits industrialized countries Parties to cut down emissions of CO2 and other greenhouse gases to their 1990 levels by the year 2000 (Grubb and Koch *et al.*, 1993). It is less defensible and relevant for developing countries, however, which are still at an early stage of economic development (Blitzer *et al.*, 1992).

4.1 Carbon taxes, fuel-specific tax rates and energy prices

Using the CGE model, the carbon tax required to achieve a 20% cut in CO2 emissions in 2010 relative to the baseline is estimated to be 205 yuan per ton of carbon (tC).(11) For Scenario 2, which is specified to achieve a 30% cut in CO2 emissions in 2010, the carbon tax necessary is estimated to be 400 yuan/tC. Note that, unless specified otherwise, the carbon taxes estimated by our model are at current prices, i.e. they are measured at the time of carbon emissions. Table 4 converts the carbon taxes into fuel-specific *ad valorem* tax rates.(12)

Table 4 Carbon taxes and fuel-specific tax rates in 2010

	Scenario 1	Scenario 2
Carbon tax (yuan/tC)	205	400

Coal (%)	64.0	122.0
Oil (%)	14.4	28.2
Natural gas (%)	46.3	90.9
Electricity (%)	19.8	38.1

Two important observations can be made. First, the carbon taxes and the fuel-specific tax rates differ significantly among the two scenarios. As can be seen, a larger absolute cut in CO2 emissions will require a higher carbon tax. A higher tax also implies higher fuel-specific tax rates because a carbon tax becomes higher relative to the baseline prices of fossil fuels. Moreover, carbon taxes and the fuel-specific tax rates rise at an increasing rate as the target of CO2 emissions becomes more stringent, indicating that large reductions in carbon emissions can only be achieved by ever-larger increases in carbon taxes. Comparing Scenarios 1 and 2, for example, shows that the carbon tax goes up to 95% while the carbon reduction increases by only 50%.

Second, although the same carbon tax is imposed in each scenario, tax rates differ considerably among different types of fossil fuels, depending on both the carbon content and the price of fuel in the absence of carbon taxes. Given that coal is the least expensive and gives rise to the highest CO2 emissions per unit of energy content of all fossil fuels, it is not surprising that coal has the highest tax rates. A surprising result is that natural gas has a higher tax rate than oil, (13) although the former has fewer CO2 emissions per unit of energy content.

This is mainly because prices of natural gas in the absence of carbon taxes (or the pre-tax price in the baseline) are not rising faster than oil prices. As a result, tax rates for gas become higher relative to its prices, although absolute levels of the tax per unit of energy content are higher for oil than for gas. As far as electricity is concerned, it is indirectly rather than directly affected by carbon taxes via the taxation of inputs used to generate electricity. This results in tax rates for electricity of about 20% in Scenario 1 and 38% in Scenario 2. They are considerably lower than those for coal, since coal accounts for only about 18% of total electric utility costs.

Imposing fuel-specific tax rates contributes in turn to increases in prices of coal, oil, natural gas and electricity. Comparing the increases in Table 5 with the corresponding fuel-specific tax rates in Table 4, we can see that, as would be expected, they are almost the same.

Notes

(11) The carbon tax is estimated by trial and error using the GAMS `SAVE' and `RESTART' options through which a solution can be saved and reused (see the GAMS manual for details (Brooke *et al.*, 1988)). Such options are to preserve information that has been expensive to produce, and thus are always used by users of large models. More specifically, by using the `SAVE' option first the baseline solution (i.e. those at a zero carbon tax) is saved as work files. Then, an input file is written, in which a carbon tax rate is specified, and which requests a separately restarted run of work files. The baseline solution is automatically used as a starting point for the carbon tax experiment. Moreover, work files can be used repeatedly with many input files containing different carbon taxes, until the carbon tax is found required to achieve a 20% cut in carbon emissions in 2010 relative to the baseline. A similar procedure is applied to the 30% cut scenario.

(12) See Zhang (1996) for converting a given carbon tax into fuel-specific *ad valorem* tax rates.

(13) The results are broadly consistent with the OECD's GREEN modelling results for North America, the Pacific and China (Burniaux *et al.*, 1991). Similar findings are also presented in the study of Ingham and Ulph (1991), who analysed the effect of carbon taxes on the UK manufacturing sector.

4.2 Macroeconomic effects

Curbing fossil fuel CO2 emissions entails some corresponding reduction in energy consumption, and consequently, a decline in production itself. Basic economic theory can provide a rough order of magnitude estimates of this effect.

According to economic theory, the elasticity of output with respect to a factor should equal the factor's share in output.(14) Based on the data of 1987 SAM for China, we calculate that the share of energy in China's GNP in the base year (1987) was 6.5%. That is, a 10% reduction in energy consumption will lead to a 0.65% decline in GNP. Table 6 shows that to achieve approximately 20% and 30% cuts in CO2 emissions in 2010 requires about 19.5% and 29.3% cuts in energy consumption respectively. Accordingly, GNP in 2010 would fall by 1.27% (19.5% × 6.5%) and by 1.90% (29.3% × 6.5%) respectively, provided that the share of energy in China's GNP remains unchanged. Comparing this with Table 6, we can see that this order of magnitude estimate of the GNP effect is about what is predicted by this model, although the absolute values of the effect differ. Greater GNP losses predicted by this model imply that the share of energy in GNP tends to rise as the target of CO2 emissions becomes more stringent. This reflects the assumed less-than-unitary elasticity of substitution between the inputs of energy, capital, and labour, such that energy has decreased less than GNP.

In addition to the GNP effect, Table 5 summarizes other main macroeconomic effects under the two scenarios. The results show that all the components of China's GNP and welfare in 2010 are negatively affected under the two CO2 constraint scenarios compared with the baseline. Exports constitute the final demand category that is reduced most.(15) Given the exogenous current account constraint, a decline in export volumes plus a rise in export prices also make import volumes decrease less than export volumes. Moreover, with the terms-of-trade improvement that tends to offset the deadweight losses arising from the imposition of carbon taxes, welfare, i.e. the change in household real income that is measured in Hicksian equivalent variation, decreases less than GNP.

As can also be seen, the level of carbon tax and the associated reductions in GNP and welfare rise as the carbon emission targets become more stringent. Moreover, it is indicated that the reductions in GNP and welfare tend to rise more sharply as the degree of the emission reduction increases. Put another way, the economic costs of incremental environmental policy actions increase with the level of emission reduction. This is reflected by, for instance, the increased elasticity of welfare with respect to emission reduction, which is 0.054 at a 20% required rate of reduction, and 0.058 at a 30% required rate of reduction. This is also reflected by the price elasticity of carbon abatement, which rises from -0.40 in Scenario 1 to -0.32 in Scenario 2. This increasing marginal cost of emission reduction implies that further reductions in CO2 emissions are becoming increasingly more difficult. This finding also corresponds to other CGE studies.(16)

Table 5 Main macroeconomic results for China in 2010
(percentage deviations relative to the baseline; -: declines)

	Scenario 1	**Scenario 2**

GNP	-1.521	-2.763
Welfare **(a)**	-1.078	-1.753
Private consumption	-1.165	-2.972
Investment	-0.686	-1.832
Exports	-5.382	-7.447
Imports	-1.159	-2.128
Energy consumption	-19.468	-29.322
CO2 emissions	-20.135	-30.112
Price elasticity of carbon abatement	-0.396	-0.317
Price of coal	64.954	123.095
Price of oil	15.296	29.144
Price of natural gas	46.813	90.564
Average price of fossil fuels	50.888	94.895
Price of electricity	22.785	43.256
Terms-of-trade	3.636	3.822
Nominal wage rate	-1.807	-3.043
Real exchange rate	-0.004	-0.021
User price of capital	-1.777	-4.228
Prices of exports	3.633	3.801
Prices of imports	-0.004	-0.021
(a) Measured in Hicksian equivalent variation.		

Notes

- (14) This can be proved as follows. Suppose that total production Q is a function of capital K, labour L, and energy E. Let the price of output be P_q and the prices of capital, labour, and energy be P_k, P_l, P_e. Denoting the elasticity of output with respect to energy by ε_{qe} and the share of energy in output by s_e, then they can be defined as:

$$\varepsilon_{qe} = \frac{\partial Q/\partial E}{Q/E} \qquad s_e = \frac{P_e E}{P_q Q}$$

According to the marginal product theory, the value of the marginal product of a factor should equal its price (Varian, 1993). Thus we have:

$$P_q \frac{\partial Q}{\partial E} = P_e$$

Substituting $\partial Q / \partial E$ into ε_{qe} and rearranging, we have:

$$\varepsilon_{qe} = \frac{\partial Q / \partial E}{Q / E} = \frac{P_e E}{P_q Q} = s_e$$

That is, the elasticity of output with respect to energy equals the share of energy in output. Similarly, we can prove that this conclusion also holds for capital and labour.

- (15) This is also observed in the CGE study of Glomsrød *et al.* (1992), who analysed the economic effects of stabilizing CO2 emissions on the Norwegian economy.
- (16) See, for example, Conrad and Schröder (1991) for Germany; Jorgenson and Wilcoxen (1993a, 1993b) for the United States; Beauséjour *et al.* (1995) for Canada; and Martins and Burniaux *et al.* (1993) for the global study.

4.3 Effects on sectoral production and employment

Table 6 presents the percentage deviations of both aggregate and sectoral gross productions compared with the baseline. As can be seen, aggregate gross production tends to contract at an increasing rate as carbon dioxide emission targets become more stringent. However, changes in gross production vary significantly among sectors in both absolute and relative terms. The differing sectoral effects arising from the imposition of the carbon tax can be explained as follows. Meeting carbon emission targets via a carbon tax increases the prices of directly affected goods, such as coal, oil, and natural gas.

As shown in Table 4, the more stringent the carbon emission targets, the more their prices increase. As prices rise, demand for the directly affected goods falls. A carbon tax also indirectly affects the prices of goods that utilize the targeted goods as factors in their production. For instance, Table 5 shows that the price of electricity in 2010 will rise by 23% in Scenario 1 and by 43% in Scenario 2 as an indirect effect brought about by increases in prices of fossil fuel input compared with the baseline, although carbon taxes are not directly imposed on electricity. This indirect price effect exerts a further negative impact on gross production. Clearly, the combined direct and indirect effect will lead to a shift away from high-carbon energy, away from energy towards capital and labour, and away from carbon intensive goods and services, although such shifts depend on the ability of producers and consumers to change to goods that are affected to a lesser extent by a carbon tax.

As shown in Table 5, the largest increase occurs in the price of coal in percentage terms as a result of the imposition of carbon taxes. It rises by 65% in Scenario 1 and by 123% in Scenario 2 relative to that of the baseline. In response to this price change, we expect that the coal sector is affected most severely in terms of the extent to which gross output falls under the two CO2 constraint scenarios. This is confirmed in Table 6, which shows that gross production of the coal sector falls by as much as 26% in Scenario 1 and by 38% in Scenario 2. As would be expected, the substantial reduction in production growth will lead to a considerable decline in employment: the total number employed in the coal sector falls by 25% in Scenario 1 and by 36% in Scenario 2.

Table 6 Sectoral gross production in 2010
(percentage deviations relative to the baseline; -: declines)

	Scenario 1	**Scenario 2**
Agriculture	-0.486	-0.281
Heavy industry	-2.463	-3.274
Light industry	-0.616	-0.416
Transport & Communication	-0.864	-14.146
Construction	-0.723	-1.444
Services	1.709	5.528
Coal	-26.498	-38.131
Oil	-2.072	-8.540
Natural gas	-20.781	-31.897
Electricity	-6.077	-10.722
Average - all sectors	-1.046	-1.900

The reduction in gross production in the natural gas sector is second largest. (17) This is a rather surprising result, since natural gas, with the lowest CO2 emissions per unit of energy content, might be expected to benefit relatively from the imposition of carbon taxes. The main explanation is that gas has the second highest tax rates, thus making the increase in the price of gas far larger than that of oil in percentage terms. This, as discussed earlier, can be attributed to the fact that prices of natural gas in the absence of carbon taxes are not rising very sharply. The considerable fall in production has a substantial negative effect on the employment in the gas sector, which is expected to fall by 20% in Scenario 1 and by 31% in Scenario 2.

Gross production also falls in the oil and electricity sectors. Because all of the four energy sectors are capital intensive, relatively large amounts of capital are released from these sectors. Given that the total amounts of capital available to the economy are fixed, the only way for all this additional capital to be absorbed in other sectors is for the relative price of capital to decrease. This explains why the user price of capital falls even faster than the wage rate in Scenario 2 as shown in Table 5.

In contrast to these negatively affected sectors, gross production increases are observed for the service sector. Moreover, the expansions rise at an increasing rate as carbon dioxide emission targets become more stringent. This is partly because the service sector utilizes a small proportion of intermediate inputs both directly and indirectly affected.

The second reason is due to the output effect. As shown in Table 6, gross production falls in all sectors but the service sector. As a result, capital and labour are released from these sectors. Because factor supplies are fixed, the released amounts of capital and labour have to be absorbed in the service sector. Moreover, the more stringent the carbon dioxide emission targets, the more amounts of capital and labour have to be absorbed in the service sector and hence the more rapidly its production grows. The more rapid production growth in the sector relative to the baseline will lead to higher employment, which is expected to rise by 2% in Scenario 1 and by 6% in Scenario 2.

All in all, sectoral production and employment change much more than the aggregated macro variables. With the CO2 constraints, the economy restructures towards labour-intensive sectors. This will come at the cost of lower GNP and welfare, provided that the tax revenues are retained by the government.

Notes

(17) This is also observed in the study of Ingham and Ulph (1991), who analysed the effect of carbon taxes on the UK manufacturing sector.

4.4 Effects on energy consumption and CO2 emissions

Table 5 shows that to achieve approximately 20% and 30% cuts in CO2 emissions in 2010 requires about 19.5% and 29.3% cuts in energy consumption respectively. According to Bergman (1988) and Bergman and Lundgren (1990), the energy consumption reduction can be achieved through a change in level and structure of economic activity, a change in energy input coefficients, and through a change in direct energy consumption by households.(18)

Table 7 clearly indicates the relative importance of each adjustment mechanism in terms of its contribution to energy consumption reduction in 2010. The results suggest that the overwhelming energy reduction is attributed to lower energy input coefficients under the CO2 constraint scenarios compared with the baseline. But as the target of CO2 emissions becomes more stringent, its role in reducing energy consumption becomes less because of the increased contribution by a change in level and structure of economic activity. The contribution by direct energy consumption by households remains almost unchanged.

Table 7 Breakdown of the contribution to energy consumption reduction in 2010 (%)

	Scenario 1	**Scenario 2**
Due to change in aggregate production	4.69	5.66
Due to change in composition of aggregate production	9.80	13.76
Due to change in energy input coefficients	84.42	79.50
Due to change in direct energy consumption by households	1.10	1.09

Total change	100	100

Tables 8 and 9 show the percentage deviations of both sectoral energy consumption and CO2 emissions as a result of the imposition of carbon taxes compared with the baseline. Four remarks can be made here.

Table 8 Sectoral energy consumption in 2010
(percentage deviations relative to the baseline; -: declines)

	Scenario 1	**Scenario 2**
Agriculture	-0.486	-0.281
Heavy industry	-25.087	-35.827
Light industry	-26.163	-37.295
Transport & Communication	-15.983	-33.579
Construction	-15.011	-22.644
Services	-20.189	-27.402
Coal	-43.592	-59.028
Oil	-7.298	-16.565
Natural gas	-34.538	-50.330
Electricity	-21.205	-31.744
Households	-1.680	-2.504
Total **(a)**	-19.468	-29.322

(a) The corresponding price elasticity of energy consumption is -0.38 in Scenario 1 and -0.31 in Scenario 2.

First, as can be seen, energy consumption is reduced in all sectors. Accordingly, CO2 emissions fall in all sectors. Looking at the rates of reduction for both sectoral energy consumption and CO2 emissions, we can see that these are similar in both size and ranking across sectors. This implies that the amount of carbon emitted per unit of the sector's energy use remains largely unchanged.

Second, in relative (percentage) terms, energy consumption in the coal sector and the corresponding CO2 emissions in 2010 are reduced most under both scenarios. This is because the largest increase in the price of coal leads to the largest decrease in the demand for it. In contrast to the largest effect on the coal sector, a slight reduction is observed for households. This is because the carbon taxes are applied only to industries for their use of fossil fuels, and not to households for their final energy demand.

Third, the reduction in total CO2 emissions is larger than the reduction in total energy consumption. This is due to a shift in fuel consumption away from coal towards oil as shown in

Table 10, the latter being less carbon-polluting than coal. Moreover, the larger the reduction in CO2 emissions, the larger the extent to which such fuel switching takes place.

Fourth, the price elasticity of energy consumption rises as the carbon emission targets become more stringent, so does the price elasticity of carbon abatement because of the increasing marginal cost of emission reduction.

Table 9 Sectoral CO2 emissions in 2010
(percentage deviations relative to the baseline; -: declines)

	Scenario 1	Scenario 2
Agriculture	-0.486	-0.281
Heavy industry	-25.779	-36.729
Light industry	-26.703	-38.038
Transport & Communication	-17.277	-35.097
Construction	-16.230	-24.275
Services	-21.344	-29.033
Coal	-43.765	-59.237
Oil	-7.657	-17.019
Natural gas	-34.027	-49.657
Electricity	-21.606	-32.305
Households	-1.675	-2.497
Total	-20.135	-30.112

Table 10 Breakdown of fossil fuel use in 2010 (%)

	Baseline	Scenario 1	Scenario 2
Coal	74.0	69.2	67.5
Oil	22.1	26.9	28.7
Natural gas	3.9	3.9	3.8
Total fossil fuel	100.0	100.0	100.0

Table 11 Contribution by fuel user to CO2 emissions reduction in 2010 (%)

	Scenario 1	Scenario 2
Agriculture	0.023	0.009

Heavy industry	49.675	47.325
Light industry	4.613	4.394
Transport & Communication	9.164	12.448
Construction	2.531	2.531
Services	7.698	7.001
Coal	7.092	6.418
Oil	1.396	2.074
Natural gas	0.128	0.125
Electricity	16.581	16.578
Households	1.100	1.097
Total	100	100

Tables 11 shows the contribution by each fuel user to CO2 emissions reduction in 2010. This depends on both the carbon intensity of each sector and the change in level of economic activity. The higher the carbon intensity of one sector and the larger the reduction in its activity level, *ceteris paribus,* the bigger will be the contribution by that sector to CO2 emissions reduction. The combined effects make, in absolute terms, that the largest reductions occur in the heavy industry. As can be seen, almost half of the total reduction is realized in this sector. The contribution by the electricity sector ranks second, which is expected to be about 17% under both scenarios. In contrast to these large contributors, the contribution by households and agriculture is negligible, which together contribute to only about 1% of total reduction in CO2 emissions.

Notes

(18) See Zhang (1996) for calculating the contribution of each adjustment mechanism to energy consumption reduction as a result of the imposition of carbon taxes.

5 Carbon tax revenue recycling scenarios

Imposing a carbon tax will raise government revenues. As Table 12 shows, a carbon tax of 205 yuan per ton of carbon would raise an additional government revenue of 261.3 billion Chinese yuan in 2010, while the corresponding amount of revenue for a carbon tax of 400 yuan/tC would be 448.5 billion Chinese yuan. Measured as a percentage of GNP in 2010, these government revenues correspond to 1.4% and 2.4% respectively. These amounts are certainly not negligible. How these revenues are used will affect the overall economic burden of carbon taxes. In this section, we will consider uses of these revenues raised to reduce the adverse effects of the carbon taxes discussed in the previous section by reducing inefficiency elsewhere in the economy.

With respect to the uses of the revenues, there are many alternatives. Zhang and Folmer (1995a) and Zhang (1996) have argued that the macroeconomic effects of offsetting carbon tax revenues with reductions in indirect taxes are more positive than in other tax offset cases. Thus, this will probably be the most likely use of the revenues. For this reason, we have adopted this option.

To determine how large the efficiency improvement might be by this option, four tax reform simulations are constructed.

Reforms 1a and 1b are based on Scenario 1. This means that the level of carbon tax in Reforms 1a and 1b is the same as in Scenario 1, which is 205 yuan per ton of carbon as shown in Table 13. But in the two simulations, part of the carbon tax revenues is recycled into the economy by means of equally reducing indirect taxes by 5% and 10% respectively.

Similarly, Reforms 2a and 2b are based on Scenario 2. They maintain the carbon tax of Scenario 2, but indirect tax rates for all sectors are equally reduced by 5% and 10% respectively.

Table 12 Government revenues in 2010

	Baseline	**Scenario 1**	**Scenario 2**
Cut in CO2 emissions **(1)**	-	-20.1	-30.1
Government revenues **(2)** of which	42642.8	44569.0	45769.7
Indirect tax **(2)** Carbon tax **(2)** Carbon tax revenues/GNP (%)	22525.7 - -	22247.0 2613.0 1.4	22043.7 4485.5 2.4
Change in government revenues **(1)**	-	4.5	7.3

(1) Percentage deviations relative to the baseline (-: declines);
(2) Measured in 100 million yuan.

Table 13 shows results in 2010 of the two simulations based on Scenario 1. Because there is a slightly smaller reduction in CO2 emissions in Reforms 1a and 1b than in Scenario 1, the carbon tax revenues from Reforms 1a and 1b are slightly higher than Scenario 1. Moreover, as a result of the reduction in indirect tax rates, the total government revenues fall by 2.2% for Reform 1a and by 4.2% for Reform 1b relative to Scenario 1. The larger reduction in the revenues from Reform 1b is due to a larger reduction in indirect tax rates in Reform 1b than that in Reform 1a. With respect to the GNP effect, our results show that a 1.52% GNP loss under Scenario 1 is converted to a 1.51% loss in Reform 1a and a 1.47% loss in Reform 1b.

These results suggest increased improvement in GNP if a larger reduction of indirect tax rates took place, although the improvement is small. The improvement is due to an increase in private consumption and international competitiveness of Chinese industries. By contrast, the welfare effect is markedly improved. As can be seen, a 1.08% loss under Scenario 1 is converted to a 0.41% loss in Reform 1a and even a 0.23 gain in Reform 1b.

Table 13 Selected results for revenue experiments in 2010, related to Scenario 1

	Scenario 1	**Reform 1a**	**Reform 1b**
Cut in CO2 emissions **(1)**	-20.13	-20.06	-19.93

Carbon tax (yuan/tC)	205	205	205
Real GNP **(1)**	-1.52	-1.51	-1.47
Welfare **(1,2)**	-1.08	-0.41	0.23
Private consumption **(1)**	-1.17	-0.52	0.13
Exports **(1)**	-5.38	-5.19	-4.97
Government revenues **(3)** of which	44568.96	43576.31	42686.11
Indirect tax **(3)** Carbon tax **(3)**	22247.03 2613.03	21112.22 2616.56	20075.2 2621.67
Change in government revenues **(1)**	4.52	2.19	0.10
Change in government revenues **(4)**	-	-2.23	-4.22

(1) Percentage deviations relative to the baseline (-: declines);
(2) Measured in Hicksian equivalent variation.
(3) Measured in 100 million yuan;
(4) Percentage deviations relative to Scenario 1 (-: declines).

Table 14 tells the same story, showing those results of the two simulations based on Scenario 2, although they are numerically different from the results for Reforms 1a and 1b. One important feature of the two simulations is the large improvement in GNP and welfare relative to Scenario 2, particularly for Reform 2b. This means that as the target of CO2 emissions becomes more stringent, the positive effects of offsetting the carbon tax revenues with reductions in indirect taxes on GNP and welfare become more notable. This has been clearly shown in Figures 3 and 4, which illustrate the effects of reductions in indirect tax rates ranging from zero to 12% on GNP and welfare.

As can be seen, a larger reduction of indirect taxes leads to a less negative economic growth and better welfare compared with the baseline. This finding has an important policy implication, as it suggests that if the target of CO2 emissions becomes more stringent (i.e. fossil fuels are taxed more heavily by carbon taxes), it will become more worthwhile to lower indirect taxes in order to reduce the adverse effects of a carbon tax.

Table 14 Selected results for revenue experiments in 2010, related to Scenario 2

	Scenario 2	**Reform 2a**	**Reform 2b**
Cut in CO2 emissions **(1)**	-30.11	-30.01	-29.16
Carbon tax (yuan/tC)	400	400	400
Real GNP **(1)**	-2.76	-2.75	-2.18
Welfare **(1,2)**	-1.75	-1.09	-0.25
Private consumption **(1)**	-2.97	-2.33	-0.91
Exports **(1)**	-7.45	-7.23	-6.10

Government revenues **(3)** of which	45769.74	44791.17	44181.26
Indirect tax **(3)** Carbon tax **(3)**	22043.67 4485.49	20919.40 4493.53	19877.03 4555.67
Change in government revenues **(1)**	7.33	5.04	3.61
Change in government revenues **(4)**	-	-2.14	-3.47

(1) Percentage deviations relative to the baseline (-: declines);
(2) Measured in Hicksian equivalent variation.
(3) Measured in 100 million yuan;
(4) Percentage deviations relative to Scenario 1 (-: declines).

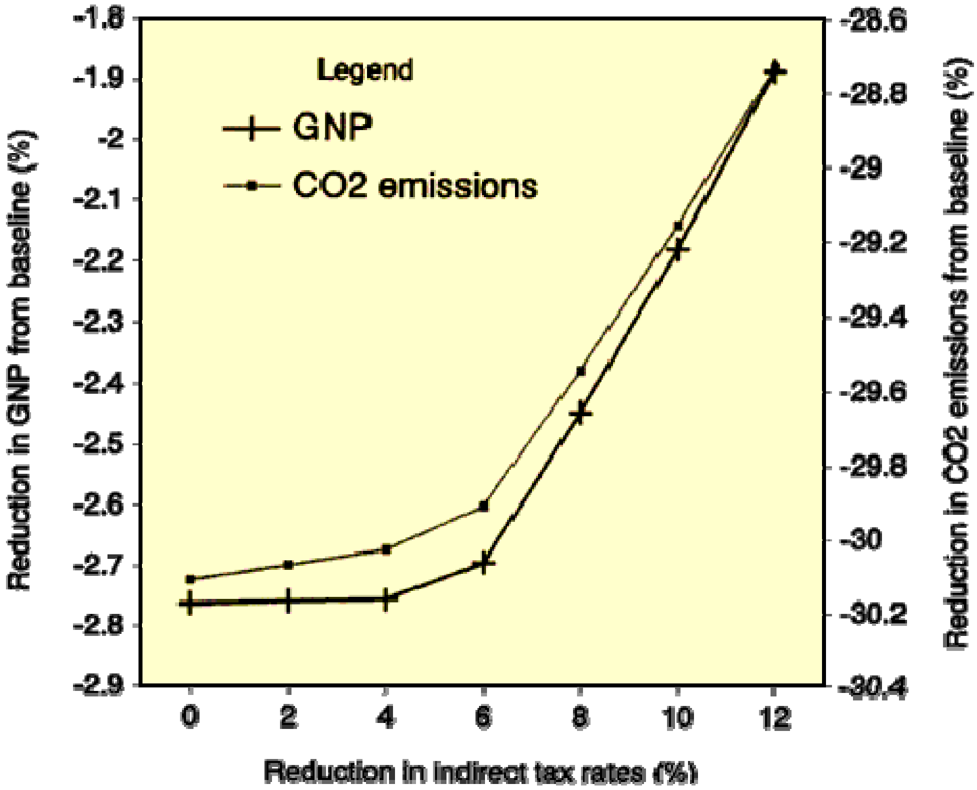

Figure 3 GNP effect of indirect tax offset relative to Scenario 2

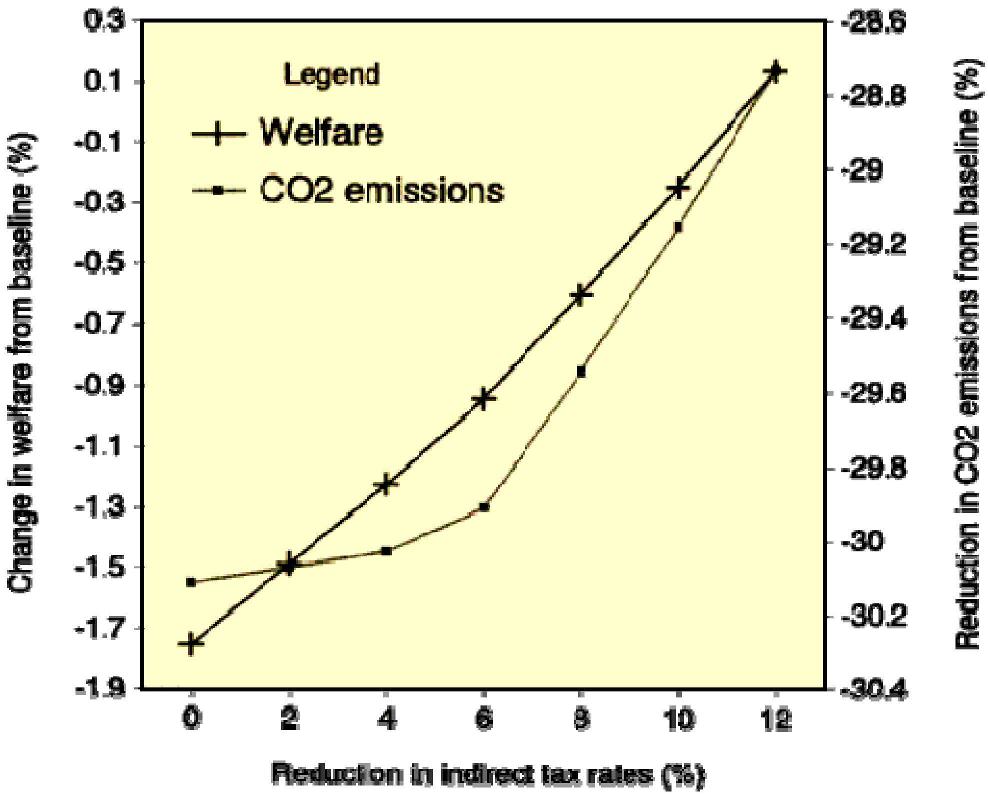

Figure 4 Welfare effect of indirect tax offset relative to Scenario 2

6 Comparison with other studies for China

Several studies have already addressed the issue of fossil fuel CO2 emissions in China and/or of cost of their reductions. In this section, we will compare our results with those obtained by others, in terms of both the baseline scenarios and the carbon constraint ones.

Other studies considered for comparison include not only the well-known global studies based on GLOBAL 2100 and GREEN, but also the single-country studies by the US Argonne National Laboratory (ANL) and the Chinese Academy of Social Sciences (CASS). Prior to the comparison, we describe only briefly the these studies.

Because of the global characteristics of climate change and China's potential importance as a source of CO2 emissions, there exist, though relatively few, global models that cover various political-economic regions and that treat China as a separate region. Global models in this tradition include the well-known GLOBAL 2100 (Manne and Richels, 1991a, 1991b, 1992; Manne, 1992) and GREEN (Burniaux *et al.*, 1992). The so-called GLOBAL 2100 model, with a dynamic nonlinear optimization framework of the maximization of discounted utility, is based on parallel independent computations for five major geopolitical regions: the USA, other OECD nations, the former USSR and Eastern Europe, China and the rest of world.

The model has a rich treatment of the energy sector but a highly aggregated description of the economy. It can be run as far into the future as the year 2100, in eleven steps of ten-year intervals. So far, GLOBAL 2100 has been considered to be the most complete global model within an optimization framework in terms of modelling the energy sector and its feedback to aggregate output. Using this model, Manne and Richels (1991a, 1992) and Manne (1992) analyse the abatement costs under alternative CO2 emission limits, and carbon tax rates necessary for achieving large CO2 reductions and the feedback impacts of rising energy costs. Manne and Richels (1991b, 1992) also quantify the potential for international trade in CO2 emission permits.

GREEN (GeneRal Equilibrium ENvironmental model) is a multi-sector, multi-region, dynamic CGE model used for evaluating the economic costs of international agreements to curb global CO2 emissions. It has full clearing markets and is made up of twelve regions. So far it has been the most complete global CGE model in terms of fuel, regional and sectoral disaggregations and the modelling of backstop technologies. Currently, GREEN is being simulated over the period 1985-2050, in five steps of five-year intervals up to 2010 and two further steps of twenty-year intervals. Given the recursive structure of the model, the evolution over time of the economy is described as a sequence of single-period static temporary equilibria. The model has been used, among other things, to simulate the economy-wide impacts of a variety of international agreements on curbing CO2 emissions.

The ANL study is based on China's dynamic linear programming model, which has been adapted from the Dervis *et al.* (1982) model and aims to analyse the growth effect of various CO2 mitigation strategies (Rose *et al.*, 1994). The CASS study, which is not a carbon abatement cost study, is based on China's system dynamics model and aims to forecast economic and social development in China under various circumstances (Yao *et al.*, 1994). Because these two single-country studies do not simulate the economic adjustment of a carbon tax, they are only referred to when comparing the baseline scenarios.

6.1 Comparison of the baseline scenarios across models

We start with comparing the baseline scenarios across models. Table 15 summarizes the results for the baseline scenarios across models.

As Table 15 shows, both GLOBAL 2100 and GREEN project very low growth rates of CO2 emissions in China over the period 1990 - 2010. The results are as expected because both models set exogenously a very low growth rate of real GDP for China as specified by the Energy Modelling Forum at Stanford University, (19) i.e. at 4.25% per annum during this period. Given that the target planned by the Chinese government is 8% to 9% annually over the period 1990 - 2000, which implies an annual growth rate of 3.9% to 4.4% over the period 1990 - 2010 even if zero rate of economic growth took place over the period 2000-10, the assumption about GDP growth in GLOBAL 2100 and GREEN is thus considered most unrealistic.

Consequently, the baseline carbon emissions as estimated by GLOBAL 2100 and GREEN should be regarded as most optimistic from the point view of CO2 emissions. By contrast, the baseline CO2 emissions estimated in the ANL study are the highest. This is also not surprising because energy conservation plays only a limited role in reducing CO2 emissions in the ANL study, so that its baseline carbon emissions rise at almost the same rate as GDP. Given the optimistic economic growth and the most pessimistic view of energy conservation potential in the ANL study, the baseline emissions should be regarded as a worst-case scenario from the point view of CO2 emissions.

By comparison with the two extremes above, the baseline CO2 emissions estimated in the CASS study and by our model are in the middle of the pack. Comparing our results with the CASS results, however, we think that the latter are relatively optimistic in terms of both economic growth and energy conservation. In the CASS study, economic growth is estimated to be 8.8% annually over the period 1990 - 2010, which is on the high side of 8% to 9% planned for the period 1990 - 2000, and there is also a lack of backing from conventional wisdom for its energy conservation rate. In addition, the CASS study estimates the increased carbon intensity of energy use during the period under consideration. This contrasts sharply with the general finding that the carbon intensity of energy use is expected to be reduced, although the extent of such a reduction is not very large (see e.g. Zhang (1991), EWC/ANL/TU (1994) and this paper).

From the preceding discussion, it thus follows that our estimates of the baseline CO2 emissions represent the most plausible cases of all the models considered, although they are not a projection of what would actually happen in China if carbon emissions restriction was not imposed.

Table 15 A comparison of the baseline scenarios across models in 2010

	Our CGE model	**GLOBAL 2100**	**GREEN**	**ANL**	**CASS**
CO2 emissions (MtC) **(a)**	1441.3	937.0	1363.0	1959.0	1427.0
Growth rate of CO2 emissions (%) **(b)**	4.59	1.92	4.12	7.73	5.07
Growth rate of GNP (%) **(b)**	7.95	4.25	4.25	8.00	8.80
Energy conservation rate (%) **(b)**	2.84				3.72
Change rate of CO2 emissions per unit of energy use (%) **(b,c)**	-0.28				0.32

(a) CO2 emissions in the ANL are measured in tons of carbon dioxide. Divide by 3.67 to convert to tons of carbon.
(b) Average annual rate over the period 1990 - 2010.
(c) -: declines.

Sources: Manne (1992); Martins and Burniaux *et al.* (1993); Rose *et al.* (1994); Yao *et al.* (1994); Own calculations.

Notes:

(19) This is the so-called EMF-12 study. For models participating in EMF-12, including GLOBAL 2100 and GREEN, the common assumptions about e.g. GNP growth rate for each region have been adopted. For a complete description of EMF-12, see Gaskins and Weyant (1993).

6.2 Comparison of the carbon constraint scenarios across models

Let us now compare the results for the carbon constraint scenarios. As mentioned earlier, because these two single-country studies do not simulate the economic adjustment of a carbon tax, a comparison of the carbon constraint scenarios only takes place between the global studies and our study.

Using GLOBAL 2100 benchmarked against the 1990 base year, Manne (1992) estimates, among other things, a GDP effect of 1% and 2% annual reductions in the rate of CO2 emissions growth relative to the baseline. In absolute terms, these are equivalent to a 18.0% cut and a 32.7% cut in CO2 emissions in 2010 relative to the baseline. Table 16 shows the results of the two simulations labelled as Scenarios 1% and 2% respectively. To allow the results to be compared more easily with our results, we interpolate the carbon taxes required and the associated GDP losses from achieving the same reductions in CO2 emissions as those in our study, assuming that the change in carbon tax and the GDP effect are linear with respect to the magnitudes of reductions in carbon emissions.

The results are given in parentheses in Table 16. This table also shows the simulation results of the 1% and 2% annual reductions in baseline carbon emission growth using GREEN as well as the required carbon taxes and the associated GDP losses converted to achieve the same carbon reductions as those in our study.

From Table 16, it can be seen that our estimates of a reduction in GNP growth are higher than those by GLOBAL 2100 and GREEN. Although it is difficult to provide a completely rigorous explanation for the differences between these results, there are possibilities of identifying the sources of the differences, if not to quantify their significance.

First, the economic costs of a carbon constraint are determined to a large extent by the baseline of CO2 emissions. The more rapid the growth of uncontrolled emissions under business-as-usual, the larger the size of the gap between uncontrolled emissions and a particular target and hence the higher the costs to meet the target. Given that our baseline of carbon emissions is higher than that in GLOBAL 2100 and GREEN, it should thus come as no surprise that our estimates of GNP loss are higher than those by GLOBAL 2100 and GREEN.

Table 16 A comparison of CO2 emission reductions, carbon taxes and growth effect across models in 2010

	CO2 emissions (a)	**Carbon tax (b)**	**GNP (GDP) (a)**
GLOBAL 2100 **(c)**			
Scenario 1%	-18.036	57.999	-0.783
Scenario 2%	-32.657	165.837	-2.127
Scenario 1	(-20.135)	(73.480)	(-0.976)
Scenario 2	(-30.112)	(147.066)	(-1.893)
GREEN **(c)**			
Scenario 1%	-17.535	8.000	-0.200
Scenario 2%	-32.135	20.000	-0.500
Scenario 1	(-20.135)	(10.137)	(-0.253)
Scenario 2	(-30.112)	(18.337)	(-0.458)

Our CGE model			
Scenario 1	-20.135	17.929	-1.521
Scenario 2	-30.112	34.983	-2.763

(a) Percentage deviations relative to the corresponding baseline (-: declines);
(b) Measured in US dollars per ton of carbon. In GLOBAL, carbon taxes are measured at 1990 prices, in GREEN at 1985 prices, and in our model at 1987 prices;
(c) The figures in parentheses result from interpolating the carbon taxes required and the associated GDP losses that have originally been estimated by GLOBAL 2100 and GREEN in order to achieve the same carbon reductions as those in our study.

Sources: Manne (1992); Martins and Burniaux *et al.* (1993); Own calculations.

The second reason is related to the sectoral aggregation of the Chinese economy. Our model is much disaggregated compared with GLOBAL 2100, the latter including a macroeconomic growth model with only one final output good in its highly aggregated representation of the economy. Our model is also relatively disaggregated compared with GREEN, the production block of which includes only eight sectors. This implies less substitutability in our model and hence leads to higher economic costs, since the implicit assumption of aggregation is that all output and resources within one aggregate are perfect substitutes.

The third reason is related to the model type. Our model is a single-country CGE model. It is able to calculate the economic effects of unilateral carbon taxes on China, assuming that its trade partners do not react to carbon taxes. By contrast, GREEN is a global CGE model, with China being treated as a separate region. This global model allows for computing regional economic implications of region-specific carbon taxes under the assumption that all trade partners do react to carbon taxes, although the extent of reaction may vary significantly among partners. Because the global model takes into account actions of all trade partners, this may make its results different from those of a single-country model.

For instance, although both GREEN and our model estimate that the coal sector in China is affected most severely as a result of the imposition of carbon taxes, their estimates of the effect on energy intensive industry quite differ. In our model, the energy intensive industry (the heavy industry) in China is estimated to be negatively affected by the imposition of unilateral carbon taxes because this sector uses a large proportion of intermediate inputs both directly and indirectly, while in GREEN, its output is virtually unchanged (Burniaux *et al.*, 1991) because of the relative improvement in Chinese energy intensive goods' competitiveness via trade reallocation.

The differing effects brought about by the imposition of unilateral carbon taxes or by the imposition of regional carbon taxes may partly explain why the estimates of China's GNP loss by our model are lower than those by GREEN. This suggests that the economic cost of carbon abatement in China would not appear to be that high if actions of its trade partners were taken into account. This finding is also consistent with results from studies based on the game theory, which demonstrate that cooperative outcomes are better than noncooperative ones in terms of the cost-effectiveness of emission reduction (cf. Barrett, 1990).

Let us now explain the differences between the carbon taxes required across models.

First, the magnitude of the carbon tax depends on the size of the gap between uncontrolled emissions and a particular target. The larger the gap, the more carbon is to be reduced to meet the emission target and hence the higher will be the carbon tax required. This explains why our estimates of carbon tax are higher than those by GREEN and why a larger absolute cut in CO_2 emissions will require a higher carbon tax, as shown by the estimates with GLOBAL 2100 and our model. When explaining why GLOBAL 2100 gives higher carbon taxes than our model, however, this explanation does not hold. We will come back to this issue later.

Another reason why the carbon tax is lower in GREEN than that in our model is related to the benchmark value of domestic energy prices in China. In GREEN, although the year 1985 is chosen as the base year, China's input-output table for 1981 is used, while in our model China's 1987 input-output table is used. Given that fossil fuels, particularly coal, were more heavily subsidized in 1981 than in 1987, (20) it is not surprising that GREEN requires lower carbon taxes than our model, because GREEN has lower baseline prices of fossil fuels.

Let us return to the carbon tax level of GLOBAL 2100. There have been a number of critiques of the study of Manne and Richels (1990). These critiques include that of Williams (1990), Hogan (1990) and Morris *et al.* (1991), who considered that the carbon tax level estimated by GLOBAL 2100 is too high. Here we mention two factors that are of crucial importance for the high carbon tax level of GLOBAL 2100. (21)

The first factor is the autonomous energy efficiency improvement (AEEI). This parameter is considered to be crucial to limiting the tax level required. In a series of studies based on GLOBAL 2100 (Manne and Richels, 1990, 1991a, 1991b; Manne, 1992), however, Manne and Richels have been unduly pessimistic in choosing the values of the AEEI parameter. For instance, Manne (1992) assumes that for China the AEEI is 1% per year. This value is much lower than 3.6% observed over the period 1980-90 (Zhang and Folmer, 1995b). The assumed low value of the AEEI parameter makes energy conservation as modelled in GLOBAL primarily a result of the imposition of a carbon tax. This in turn would lead to a high level of carbon taxes in order to reduce CO_2 emissions to the target level.

Second, the abatement options considered and the estimated costs of the options will also affect the carbon tax rates required. As discussed in Manne and Richels (1992), the core of GLOBAL 2100 is the ETA module with the explicit, process-oriented description of energy supply technologies. Williams (1990) thinks that the options for reducing CO_2 emissions are much broader than those considered by Manne and Richels (1990). Moreover, Williams argues that ETA may overstate the costs of important alternative low carbon-polluting energy technologies because no account is taken of near-term opportunities for cost reduction for these options. Where there are few economically feasible substitutes available, the effectiveness of a carbon tax is likely to be much more limited. Thus, in order to make these alternative technologies become competitive with traditional high carbon-polluting technologies, a higher carbon tax is required than would otherwise have been the case.

Despite numerical differences across models in the carbon tax rates and their associated costs, the following consensuses emerge: (22)

First, a larger absolute cut in CO_2 emissions will require a higher carbon tax. Moreover, carbon tax rises at an increasing rate as the target of CO_2 emissions becomes more stringent, indicating that large reductions in carbon emissions can only be achieved by ever-larger increases in carbon taxes.

Second, the associated GNP losses rise as the carbon emission targets become more stringent. Moreover, they tend to rise more sharply as the degree of the emission reduction increases.

Third, China would be one of the regions hardest hit by carbon limits. This is reflected by the fact that China's GNP losses under less restrictive carbon limits are in the same range as the often reported estimates for industrialized countries under very restrictive carbon limits. This, combined with the industrialized countries being responsible for the majority of global CO2 emissions, explains the Chinese government stance in carbon abatement.

Note that the preceding discussion focuses on China. Nevertheless it is worthwhile comparing the magnitude of carbon tax across regions because it forms a basis for China's development of *joint implementation* projects with other countries. Using the same labels as those in Table 16, Table 17 shows the carbon taxes across regions of the 1% and 2% annual reductions in baseline carbon emission growth using GREEN, as well as the required carbon taxes converted to achieve the same carbon reductions as in our study, the latter given in parentheses.

Comparing the carbon tax levels in Table 17 with those in Table 16, we can see that the carbon taxes required in China are much lower than for both the industrialized countries and the world average in order to achieve the same emission reductions relative to the baseline. This significant differences in carbon tax levels across regions point to opportunities for international trade in carbon emission permits to reduce the global costs of abating CO2 emissions. However, it is unlikely that a global regime of tradeable carbon permits will emerge in the near future.

Thus, as a preliminary step towards that regime, *joint implementation* mechanism, although not without conceptual problems, (23) should be considered a means of reducing global CO2 emissions effectively. This mechanism will not only help China, which is becoming an important source of future CO2 emissions, alleviate the suffering from possible future carbon limits, but also act to lower the costs of undertaking carbon abatement in the industrialized countries that are currently responsible for the majority of global CO2 emissions and hence to reduce the competitive disadvantage and carbon leakage associated with purely unilateral policies in these countries. Worldwide, this will achieve global carbon abatement at a lower overall cost than would otherwise have been the case.

Table 17 Carbon taxes across regions in 2010 (in 1985 $ per ton of carbon) **(a)**

	USA	**Japan**	**EEC**	**Total OECD**	**China**	**World**
Scenario 1%	39	46	71	48	8	34
Scenario 2%	139	116	180	152	20	105
Scenario 1	(53.4)	(55.9)	(85.7)	(62.7)	(10.1)	(45.1)
Scenario 2	(120.3)	(103.1)	(158.6)	(132.3)	(18.3)	(92.9)

(a) The figures in parentheses result from interpolating the carbon taxes required and the associated GDP losses that have originally been estimated by GREEN in order to achieve the same carbon reductions as those in our study.

Sources: Sources: Martins and Burniaux *et al.* (1993); Own calculations.

Notes

(20) The ratio of domestic coal price to world coal price was 0.84 in 1989 (Zhang, 1996), while the corresponding figure is only 0.45 in GREEN (Lee *et al.*, 1994). If we define fossil fuel subsidies as the difference between domestic fossil fuel prices and their world prices, this means that coal is more heavily subsidized in GREEN than in our model.
(21) For detailed critiques, see Williams (1990) and Hogan (1990).
(22) The first two consensuses are also in line with general findings from other CGE studies; see e.g. Conrad and Schröder (1991) for Germany; Jorgenson and Wilcoxen (1993a, 1993b) for the United States; Beauséjour *et al.* (1995) for Canada; and Martins and Burniaux *et al.* (1993) for the global study.
(23) Currently, policymakers are exploring opportunities for joint implementation, which might eventually lead to an international carbon emission permits market. A detailed discussion of this mechanism, however, is beyond the scope of this study. See Jepma (1995) and Michaelowa (1995) for the conceptual base, the institutional aspects and the illustrative experiences accrued thus far with respect to *joint implementation*, and Tietenberg and Victor (1994) for the implementation issues for a global tradeable carbon permits regime.

7 Concluding remarks

This study is the first systematic and comprehensive attempt to deal with the economic implications of carbon abatement for the Chinese economy. As a starting point of macroeconomic analysis of carbon emission limits, a baseline scenario has first been developed under a set of assumptions about the exogenous variables. The calculation results show that a rapid growth of the Chinese economy will take place until the year 2010. Consequently, this will lead to increased energy consumption and hence CO2 emissions, despite substantial energy efficiency improvement. Moreover, a comparison with other studies for China has shown that of all the models considered, our estimates of the baseline CO2 emissions represent the most plausible cases from the point view of CO2 emissions.

Then, using the time-recursive dynamic CGE model and assuming that carbon tax revenues are retained by the government, Section 4 analyses the implications of two scenarios under which China's CO2 emissions in 2010 will be cut by 20% and 30% respectively relative to the baseline. The two emission targets are less restrictive in that they are not compared with the level of emissions in a single base year, but with the baseline CO2 emissions in 2010, the latter being 2.46 times that in 1990. Our main findings can be summarized as follows.

First, a larger absolute cut in CO2 emissions will require a higher carbon tax. Higher tax also implies higher prices of fossil fuels. Moreover, carbon tax rises at an increasing rate as the target of CO2 emissions becomes more stringent, indicating that large reductions in carbon emissions can only be achieved by ever-larger increases in carbon taxes and hence prices of fossil fuels.
Second, even under the two less restrictive carbon emission scenarios, China's GNP drops by 1.5% and 2.8% and its welfare measured in Hicksian equivalent variation drops by 1.1% and 1.8% respectively in 2010 relative to the baseline, indicating that the associated GNP and welfare losses tend to rise more sharply as the degree of the emission reduction increases. Given the often reported losses of 1-3 per cent of GDP in industrialized countries under very restrictive carbon limits, the results also support the general finding from global studies that China would be one of the regions hardest hit by carbon limits. This, combined with the industrialized countries being responsible for the

majority of global CO_2 emissions, explains the Chinese government stance in carbon abatement.
Third, although aggregate gross production tends to decrease at an increasing rate as the carbon dioxide emission target becomes more stringent, changes in gross production vary significantly among sectors in both absolute and relative terms. Of the ten sectors considered, we found that the coal sector is affected most severely in terms of output losses under the two CO_2 constraint scenarios. Consequently, this will lead to a considerable decline in the sector's employment. This suggests that special attention should be paid to the sectoral implications when designing a domestic carbon tax.
Fourth, of the four adjustment mechanisms considered, lower energy input coefficients contribute to the bulk of energy reduction and hence CO_2 emissions in 2010 under the two CO_2 constraint scenarios, followed by a change in the structure of economic activity. With respect to the contributions to CO_2 abatement in 2010, although in relative (percentage) terms energy consumption in the coal sector and the corresponding CO_2 emissions in 2010 are reduced most under both scenarios, in absolute terms, the largest reductions occur in the heavy industry.

In Section 5, we have computed the efficiency improvement of four indirect tax offset scenarios relative to the two tax retention scenarios above. The four simulations labelled as Reforms 1a, 1b, 2a and 2b respectively show that if these revenues were used to offset reductions in indirect taxes, the negative impacts of carbon taxes on GNP and welfare would be reduced. Moreover, as shown by Reforms 2a and 2b as well as in Figures 3 and 4, the efficiency improvement tends to rise as the target of CO_2 emissions becomes more stringent (i.e. fossil fuels are taxed more heavily by carbon taxes). This suggests that it would become more worthwhile to lower indirect taxes in order to reduce the adverse effects of a carbon tax.

In Section 6, a comparison with other studies for China has been made. It has been indicated that our estimates of the reduction in GNP growth are higher than those by GLOBAL 2100 and GREEN in order to achieve the same reductions in CO_2 emissions relative to the baseline. This might be related to three factors. First, our baseline of carbon emissions is higher than that in GLOBAL 2100 and GREEN. Second, our model is relatively disaggregated compared with both GLOBAL 2100 and GREEN. This implies less substitutability in our model, leading to higher economic costs. Third, model types matter. While in our single-country model one branch of industry is estimated to be negatively affected under the carbon constraints, this would not always be the case in a global model such as GREEN because of the relative improvement in Chinese branch goods' competitiveness via trade reallocation. The differing effects brought about by the imposition of unilateral carbon taxes or regional carbon taxes could be part of the explanation for the higher GNP losses in our model.

With respect to the carbon taxes required to achieve the same carbon reductions in 2010 relative to the baseline, our estimates are on the one hand higher than those by GREEN. This is because GREEN has a smaller size of the gap between the uncontrolled emissions and the emission target, and because GREEN has lower baseline prices of fossil fuels. On the other hand, our estimates are lower than those by GLOBAL 2100. This is because GLOBAL 2100 assumes lower values of the AEEI parameter, and because GLOBAL 2100 considers limited options for reducing CO_2 emissions and overstates the costs of some important alternative low carbon-polluting energy technologies.

Finally, comparing carbon tax levels across the regions considered shows that the carbon taxes required in China are much lower than those for both the industrialized countries and the world average in order to achieve the same emission reductions relative to the baseline. This suggests that the *joint implementation* mechanism, which might eventually lead to an international carbon emission permits market, should be considered a means of reducing global CO2 emissions effectively. This mechanism will not only help China, which is becoming an important source of future CO2 emissions, alleviate the suffering from possible future carbon limits, but also act to lower the costs of undertaking carbon abatement in the industrialized countries.

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