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Controlling carbon emissions in China

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ABSTRACT. We examine the use of carbon taxes to reduce emissions of CO_2 in China. To do so, we develop a dynamic computable general equilibrium (CGE) model of the Chinese economy. In addition to accounting for the effects of population growth, capital accumulation, technological change, and changing patterns of demand, we also incorporate into our model elements of the dual nature of China's economy where both plan and market institutions exist side by side. We conduct simulations in which carbon emissions are reduced by 5, 10, and 15 per cent from our baseline. After initial declines, in all of our simulations GDP and consumption rapidly exceed baseline levels as the revenue neutral carbon tax serves to transfer income from consumers to producers and then into increased investment. Although subject to a number of caveats, we find potential for what is in some sense a 'double dividend', a decrease in emissions of CO_2 and a long run increase in GDP and consumption.

1. Introduction

China's rapid growth since the beginning of economic reform in late 1978 has been accompanied by a rapid increase in the use of fossil fuels. Over this period, the rate of increase in the use of primary energy has been about 4 per cent per year. While this is only about half the rate of increase in real national output, given the sheer size of the Chinese economy, this has led to emissions, in 1995, of some 870 million tons of carbon in the form of carbon dioxide, the main anthropogenic greenhouse gas. In the same year, by comparison, the world's largest emitter, the United States, generated an estimated 1.4 billion tons of carbon, while the world total was about 6.4 billion tons.[1]

Although there exist a wide range of plausible forecasts of future Chinese emissions, they are unanimous in predicting that China will become the world's largest emitter of CO_2 sometime within the next several decades. Our previous baseline projection, for example, puts China's annual carbon emissions at about 1.8 billion tons by the year 2020 (Ho, Jorgenson, and Perkins, 1998). Given the current interest in controlling global greenhouse gases, it is crucial to understand the workings of China's economy and its

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[1] Carbon Dioxide Information Analysis Center (1997).

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relationship to carbon emissions. In addition, there is great concern about the costs of any attempt at controlling these emissions. Is there a large tradeoff between environmental objectives and economic development? This question must be a central concern of policy makers in China.

In this paper, we discuss how carbon taxes might be used to reduce carbon emissions and the effect of such taxes on both total output and the output of individual sectors. Our goal is not only to examine the link between current fossil fuel use, carbon emissions reduction strategies, and costs in forgone output, but also to study the effects on economic growth and hence future emissions and costs. In previous work (Garbaccio, Ho, and Jorgenson (1997b) we examined the effects of economic liberalization on fossil fuel use. In this paper, we study the effects of carbon taxes on the choice of energy inputs, given a level of economic activity, and the effects of these policies over time on economic growth.

For this purpose we develop a dynamic economy–energy–environment model for China. While the model abstracts from many aspects of this complex economy, its does contain a number of features we believe are essential for capturing the policy impacts we wish to assess. Previous studies have used numerical models to examine some of these issues (e.g., World Bank (1994), Xie (1995), Rose *et al*. (1996), and Zhang (1998a, 1998b)). Like Ho, Jorgenson, and Perkins (1998), the study by the World Bank (1994) employs exogenous forecasts of technology and demand patterns to provide a range of plausible forecasts of future greenhouse gas emissions. Neither of these studies, however, attempts to estimate the effects of specific policies, such as carbon taxes, to control these emissions. Xie (1995) uses a CGE model to examine the effects of emissions taxes on pollution, including particulates, but excluding CO_2. However, while Xie's model has detailed pollution control cost functions, they are specified within a static framework. Rose *et al*. (1996) use a linear programming model to examine the output cost of reducing carbon emissions. In their simulations, they compare two economies that are optimized at each level of carbon targets. They do not, however, have an explicit role for prices and ignore the 'non-optimizing' features of the Chinese economy, such as the residual elements of the planned economy and credit controls. Zhang's (1998a, 1998b) work is the closest to our own, using a ten-sector dynamic CGE model to assess the effects of various policies designed to reduce the growth of CO_2 emissions. However, Zhang also assumes a completely marketized economy.

In the model described here we emphasize two features of the economy. First, our model is dynamic and tries to take into account the effects of population growth, capital accumulation, technology change, and changing patterns of demand. Second, we attempt to model the dual nature of the Chinese economy, whereby both plan and market institutions exist side by side. Although the scope of the plan has been drastically reduced for most commodities, it still exists for some important energy goods, such as coal and oil.[2] In addition, capital markets are still largely

[2] As of 1996, 79 per cent of agricultural products, 93 per cent of consumer goods, and 81 per cent of industrial production materials were sold at market prices (China Price Yearbook Editorial Committee, 1997). The remainder were sold at state-set or guidance prices (prices allowed to fluctuate within a narrow band).

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under government control, either directly through the state budget or indirectly through the state-owned banking system.

In our simulations, we find that to reduce emissions by 5 per cent, a unit carbon tax of about 9 *yuan* per ton (in 1992 *yuan*) would be required. This is equivalent to approximately a 7 per cent tax on the price of coal. If a tighter emissions target is imposed, higher tax rates are required. For a 10 per cent reduction in every period, a unit carbon tax of 18 to 20 *yuan* per ton is required. The effect of the imposition of the carbon tax, after the extra revenue raised is offset by a reduction in all other taxes, is to reduce household income and raise enterprise retained earnings. If there is no other offsetting government intervention, spending is shifted from consumption to investment. The higher level of investment leads in turn to higher future output. Although subject to a number of caveats which we discuss later, in some sense there is a 'double dividend', a decrease in emissions of CO_2 and an increase in GDP and consumption.

In the second section of this paper we briefly describe the modeling approach we have employed in this study. The third section gives a short description of the construction of the data base and the exogenous variables used in the model. Section 4 discusses the results of simulations where total emissions from fossil fuels are reduced through the imposition of carbon taxes. Some conclusions are given in section 5. The model is presented in more detail in an appendix.

2. A dynamic economy–energy–environment model for China

Large-scale numerical models have been used to study the use of carbon taxes to attain given emissions targets for many countries. Some examples for the United States are the Jorgenson and Wilcoxen (1992) and Goulder (1995a) models. Hoeller, Dean, and Hayafuji (1992) give a summary of the results of simulating carbon reductions using a number of models, including multi-regional models. However, with the exception of some of the work cited in the previous section, the potential costs of carbon reductions for China have not been as carefully studied as for developed country economies.[3]

Our model of the Chinese economy is somewhat similar in structure and scope to the Jorgenson and Wilcoxen model for the US, but we have tried to incorporate a number of special features of the Chinese economy. In contrast to models that use fixed coefficients and often produce high welfare costs when reducing emissions, our current model allows for substitution among the inputs (e.g., capital for energy, or oil for coal). Our model is formulated as a Solow growth model with exogenous savings rates. The growth of the economy is traced over time, taking into account population growth, capital accumulation, and technical change.

The agents in the model are: (i) households which supply labor inelastically, own part of the capital stock, and purchase goods and services; (ii) enterprises which produce commodities using inputs that are partly allocated through the plan and partly purchased in the market; (iii) the

[3] In general, in the multi-regional models the level of detail for China is not as great as that for the developed countries.

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Table 1. *Sectoral characteristics for China, 1992*

Sector	*Gross value of output (bil.* yuan*)*	*Estimated capital stock (bil.* yuan*)*	*Energy use (mil. tn. coal equivalent)*	*Output tax rate (net of subsidies)*
				%
1 Agriculture	909	407	50	1.22
2 Coal mining	76	109	44	–0.89
3 Crude petroleum	69	142	22	0.43
4 Metal ore mining	24	25	6	1.26
5 Other non-metallic ore mining	66	54	13	3.29
6 Food manufacturing	408	171	36	9.09
7 Textiles	380	166	33	3.54
8 Apparel and leather products	149	62	5	2.63
9 Lumber and furniture manufacturing	50	23	20	3.81
10 Paper, cultural and educational articles	176	112	19	2.77
11 Electric power	115	398	49	9.57
12 Petroleum refining	108	60	32	7.92
13 Chemicals	473	268	138	4.70
14 Building material	254	186	109	4.11
15 Primary metals	321	229	119	6.28
16 Metal products	141	56	23	3.25
17 Machinery	390	183	34	3.16
18 Transport equipment	163	80	5	3.17
19 Electric machinery and instruments	155	57	9	3.59
20 Electronic and communication equipment	107	52	2	2.04
21 Instruments and meters	24	13	1	3.34
22 Other industry	75	37	7	3.28
23 Construction	520	175	14	1.10
24 Transportation and communications	267	516	51	2.89
25 Commerce	635	352	14	–0.45
26 Public utilities	205	829	17	1.54
27 Culture, education, health and research	227	388	19	–0.75
28 Finance and insurance	171	74	1	4.40
29 Public administration	191	256	7	0.44
	Totals	**6,846**	**5,477**	**900**

Source: Development Research Center Social Accounting Matrix for 1992; State Statistical Bureau (1994); and author's estimates.

government which buys goods and services, imposes taxes, redistributes income, and sets down a central plan; and (iv) the foreign sector which purchases exports and supplies imports and foreign investment. The flow of payments among the various actors in the economy is summarized in the social accounting matrix (SAM) given in figure 1. (The SAM is described more fully in section 3).

The economy is divided into the 29 sectors listed in table 1. Our plan-

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Figure 1. *Summary social accounting matrix for China, 1992 (billion yuan)*

Receipts:	Expenditures: 1 Commodity	2 Activity	3 Value added	4 Households	5 Enterprises	6 Government subsidies	7 Public sector self-finance	8 Government	9 Foreign trade margins	10 Capital account	11 Rest of world	12 Totals
1 Commodity		4,182		1,246	79		106	228	0	967	518	7,326
2 Activity	6,846											6,846
3 Value Added		2,464										2,464
4 Households			1,205		446			15			4	1,670
5 Enterprises			1,259					4				1,263
6 Government subsidies		−45		−32	−27			103				
7 Pub. sect-finance				17	89							106
8 foreign trade margins	21	245		3	124					61		454
9 Foreign trade margin	0											0
10 Capital account				436	552			102			−62	1,028
11 Rest of world	458							2				460
12 Totals	7,326	6,846	2,464	1,670	1,263	0	106	454	0	1,028	460	

Source: Development Research Center Social Accounting Matrix for 1992 and World Bank (1996).

market formulation follows the theoretical work of Byrd (1989) and Sicular (1988) and the static CGE implementation of Garbaccio (1994, 1995). For those commodities and factors of production with both a market and plan component, there is a division between the two tracks. A fixed amount of total output is sold at the plan price, while the remainder is sold on the market. The market price equates demand and supply for all commodities. Marginal decisions are made on the basis of the market prices while changes in plan prices and quantities are inframarginal. In a single period, for those sectors in which both tracks exist, the net effect of the plan allocations is to create lump sum transfers between producers and consumers. However, over time, the plan allocations do affect sectoral retained earnings and investment.

The factors of production in the model are capital, labor, land, energy, and other intermediates. Given the unavailability of sectoral time series data, we use Cobb–Douglas production functions, with the coefficients changing over time so that there is both technical progress (more output with the same inputs) and biased technical change (changes in input demands unrelated to prices). This exogenous technical change is projected such that the Chinese input demands resemble the US 1992 structure in 40 years.

The use of energy in China in recent years is discussed in Garbaccio, Ho, and Jorgenson (1998). Using the 1987 and 1992 input–output tables, we show that recent declines in the energy–GDP ratio have been due mostly to a fall in the use of energy per unit of output at the sectoral (roughly two-digit) level. By contrast, very little of the change in the energy–GDP ratio has been due to changes in the composition of output. This fall in energy use cannot be plausibly explained by changes in relative prices alone and should be largely attributed to technical change (or change in sectoral composition below the two-digit level). Our projections of biased technical change allow for this trend to continue in the simulations.

The capital input for each industry consists of a plan component that is not mobile across sectors and a market component that is rented from a common capital stock. The capital stock evolves over time with new investment and depreciation. The labor input is mobile across sectors with the total supply projected using a population model. For two industries, agriculture and crude petroleum, 'land' is an input and its supply is fixed exogenously.

Consumers derive income from wages, dividends, and transfers. They make purchases at both plan and market prices. The pattern of consumption demands changes over time (due to effects other than just changes in relative prices) and this is again projected using 1992 US data. Household savings are set as an exogenous share of income and form part of national savings together with enterprise retained earnings and (net) foreign investment. Savings are used for investment in domestic capital and to finance the government budget deficit.

The government imposes taxes on enterprise capital income, sales, and imports. On the expenditure side, the government buys goods, provides subsidies and investment grants, pays interest on government bonds, and makes transfer payments. The deficit is covered by domestic and foreign

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borrowing. The modeling of imports and exports follows the standard one-country treatment and the trade and current accounts deficits are set exogenously. The evolution of the stocks of domestic and foreign debts and interest payments are treated consistently.

3. Data and exogenous variables

The primary data set for the model is built around the official Chinese input–output tables for 1992.[4] The input–output tables have in turn been used to construct the SAM for the same year (figure 1). The SAM provides a tabular snapshot of the economy for a single year. For each economic agent, there is a row that records incomes and a column that records expenditures. Our SAM allows for a distinction between commodities and activities (industries). Each activity can produce more than one commodity so that we can incorporate both the official USE (commodity by activity) and MAKE (activity by commodity) matrices.[5]

The SAM includes accounts for the household, enterprises, and the government. The capital account collects savings from households, enterprises, the government, and the rest of the world and uses those funds for investment and the financing of the government budget deficit (corresponding to equation A34 in the appendix). As an example, the bottom of the second column of the SAM shows that the total value of domestic gross output of the 29 industries is 6,846 billion *yuan*, of which 4,182 billion goes to the suppliers of intermediate goods, 200 billion to indirect taxes (net of 45 billion *yuan* of subsidies), and 2,464 billion *yuan* to workers and the owners of capital. Of this, the owners of capital (enterprises, row and column 5) receive 1,259 billion *yuan*, of which they keep 552 billion as retained earnings (including depreciation allowances). Households receive 1,205 billion *yuan* as labor income and 446 billion from enterprises as dividends and payments in kind. Of total household income of 1,670 billion *yuan*, 436 billion *yuan* is saved.

Where applicable, each cell in the commodity row is divided into a plan and market component. The original plan data are from a Chinese Academy of Social Sciences (CASS) survey of 769 state-owned enterprises which covered the years 1980–9, but have been updated to 1992. The sectors with the highest plan share are coal, oil, and electric power. The relative size of the sectors together with capital stocks and energy use data are given in table 1. The biggest end users of energy are the chemicals, building materials, and primary metals sectors.

Because the official input–output table includes only a single column of net exports, export and import data are assembled from Chinese customs statistics. Differences between the customs statistics data, which are in world prices, and the input–output table net exports, which are in domestic producer prices, are assumed to be the trade margins (both positive and negative) of Chinese foreign trade corporations.

[4] Details of the data construction and sources are given in Garbaccio, Ho, and Jorgenson (1997a). Details of the projections of many of the exogenous variables are also included.

[5] For example, the 'petroleum refining' activity produces both the 'petroleum refining' and 'chemical' commodities.

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Turning to the exogenous variables, the sectoral labor force data were put together from various Chinese sources. Projections of the future labor force are calculated from World Bank (1990) as described in Ho, Jorgenson, and Perkins (1998). The initial sectoral capital stock data are estimated using the depreciation allowances given in the input–output tables. The government deficit is set initially to current levels, but declines gradually to zero. The current account balance is set at a deficit initially, but declines to zero in 20 years. World prices of Chinese imports are projected to be the same as in the base period, except for world oil prices which are taken from projections by the US Department of Energy. Base exports grow initially at a rate of 8 per cent, but the growth rate is projected to gradually slow over the next 40 years. This growth rate is used for all goods except for oil exports which are set to zero growth. The productivity growth parameter (μ_j in the *g(t)* function in equation A3) is set such that the initial growth rate is 3 per cent per annum, the rate estimated for the aggregate economy (see Ho, Jorgenson, and Perkins, 1998). Given the lack of industry level estimates, this rate is used for all sectors.

4. Carbon taxes and emissions

In this section we describe our simulations of the use of carbon taxes (taxes of fuels based on their carbon content) to control carbon emissions in China. Although China does not currently impose carbon taxes and is unlikely to do so in the near future, it should be noted that China does have some history of using emissions charges in attempting to control the emissions of a number of pollutants, including air pollutants (NEPA, 1992, World Bank, 1997).[6] For the developed countries (i.e., Annex I countries under the UN Framework Convention on Climate Change), most studies of carbon emissions reduction policies have looked at a goal of stabilizing emissions at some target, such as 1990 emissions levels (Intergovernmental Panel on Climate Change, 1996). However, for China and other developing countries, which have much lower *per capita* emissions, there are strenuous objections to establishing these types of targets. Therefore, instead of focusing on stabilization, we look at the effects of reductions from a 'business as usual' baseline level of carbon emissions.

To provide a useful picture of the economic impact of carbon taxes, we have chosen to simulate a range of uniform reductions. To do this we first run a base case with no emissions targets and no carbon taxes. In the base case, total carbon emissions in each period may be written as

$$CAR_{base}(t) = \sum_i \theta_i (QI_{it} - X_{it} + M_{it}), \quad (1)$$

where QI_{it}, X_{it}, and M_{it} are industry output, exports and imports, respectively, of coal and oil and θ_i is the emissions coefficient by fuel type.[7]

After establishing the base case, we then run alternative simulations

[6] As to the effectiveness of emissions charges in China, Wang and Wheeler (1996) note that for water pollutants, while some provinces lag behind, on the whole the current levy system is relatively effective and has been 'accompanied by large reductions in water pollution'.

[7] Net imports of refined petroleum are also calculated and included in the total.

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where emissions of carbon dioxide are constrained to be a fraction γ for the base case in every period

$$CAR_{alt}(t) = \gamma\, CAR_{base}(t),\ t = 1, 2, \ldots, T. \tag{2}$$

All other exogenous variables and parameters are held constant. To achieve the carbon emissions target, we let the carbon tax be an endogenous variable which has the effect of raising the prices of coal and oil.[8] The imposition of the carbon tax raises additional revenue for the government. In order to keep the alternative simulations revenue neutral, we reduce all other taxes proportionately. With government deficits held constant, this means that we are keeping government spending the same as in the base case. To scale the original tax rates, we introduce an additional endogenous variable, λ_t, into the alternative system such that

$$t^k_t = \lambda_t\, t^k_o,\ t^t_{it} = \lambda_t\, t^t_{io}, \text{ etc.}, \tag{3}$$

where t^k_t is the capital income tax rate and t^t_{it} is the indirect tax rate for sector *i*. The sectoral indirect tax rates (net of subsidies) are provided in the last column of table 1. The government expenditure neutrality constraint is then set so that

$$GG_{alt}(t) = GG_{base}(t), \tag{4}$$

where *GG* is the quantity index of government purchases (equation A15 in the appendix). This keeps aggregate spending constant. The quantity of specific commodities purchased will, of course, change. To summarize, in the alternative simulations there are two additional equations, (2) and (4), and two additional endogenous variables, the tax rate per ton of carbon and λ. *GG*, an endogenous variable in the base case is made an exogenous variable in the alternative solutions. Tax rates on capital income, sales, and tariffs are made endogenous in the alternative cases.

We then compare the outcome of the alternative simulations with the base case solution. Although our base case may be of independent interest, we do not focus on it in this paper. The base case levels of output, emissions, etc., are driven by the assumptions about the exogenous variables, such as the rates of population growth and technological change. In Ho, Jorgenson, and Perkins (1998), we examined a number of plausible assumptions about the exogenous variables and produced a wide range of forecasts of the levels of output and emissions. Our assumptions about the exogenous variables in the current paper lead to fairly high average growth rates. In the base case, GDP rises at an average of 5.7 per cent per year over the first 30 years. The growth rate is higher in the beginning but gradually declines as both population and productivity growth slow in the later years. The high rate GDP growth leads to a high rate of growth of carbon emissions, averaging 3.8 per cent per year over the first 30 years.

We ran three alternative scenarios: 5 per cent, 10 per cent, and 15 per cent reductions in carbon emissions (i.e., γ = 0.95, 0.90, and 0.85). The impacts of these carbon reductions on some important variables are presented in tables 2, 3, and 4 and graphed in figures 2 through 7. The base

[8] See equations A4 and A12 in the appendix.

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Table 2. *Effects of a carbon tax on selected variables (Percentage change from base case)*

	Effect in 1st year with			*Effect in 30th year with*		
Variable	*5% emissions reduction*	*10% emissions reduction*	*15% emissions reduction*	*5% emissions reduction*	*10% emissions reduction*	*15% emissions reduction*
	%	%	%	%	%	%
GDP	−0.01	−0.04	−0.08	0.34	0.66	0.97
Consumption	−0.14	−0.29	−0.47	0.28	0.55	0.80
Investment	0.22	0.42	0.62	0.78	1.57	2.35
Primary energy	−4.71	−9.44	−14.17	−4.60	−9.21	−13.83
Market price of coal	6.05	12.88	20.63	6.69	14.32	23.09
Market price of oil	1.02	2.16	3.43	0.62	1.35	2.21
Coal output	−5.97	−11.91	−17.82	−6.50	−12.95	−19.36
Oil output	−0.83	−1.75	−2.78	−0.48	−1.07	−1.78

Source: Author's estimates.

case levels of total carbon emissions and the levels for the 5 per cent, 10 per cent and 15 per cent reduction cases are shown in figure 2.[9] For each of the reduction scenarios, the percentage change in GDP relative to the base case is shown in figure 3. In all of the alternative scenarios, there is a very small decline in GDP in the first year. However, in each case, there is an increase in the level of GDP in every year thereafter. In the 15 per cent carbon reduction case, by the thirtieth year of the simulation, the level of GDP has increased by almost 1 per cent over the baseline.

The unit carbon tax rates calculated for the three emissions reductions cases are shown in figure 4. For the 5 per cent emissions reduction case, a tax of about 9 *yuan* per ton of carbon is required in the first year of simulation.[10] Increasing the percentage reduction in emissions requires a more than proportionate increase in the unit carbon tax. Offsetting the new revenue from the carbon tax is the reduction in all other taxes by the factor λ. The value for λ in each period is graphed in figure 5. Each of the other tax rates is reduced by about 1 per cent in the simulation period for the 5 per cent carbon reduction case and by approximately 3–4 per cent in the 15 per cent case.

The imposition of the carbon tax increases energy prices and this in turn leads to increases in the prices of other goods (relative to the numeraire, the nominal wage rate). A decline in the real wage results in a fall in household income and, in the first few years of the simulations, a decline in aggregate consumption. This is shown in figure 6. However, given our assumption that the labor supply in China is inelastic, the decline in the

[9] In the base case, carbon emissions in year 2032 are 2.16 billion tons. This figure is reduced by 5 per cent, 10 per cent and 15 per cent in the alternative simulations.

[10] There are 0.518 tons of carbon emitted per ton of average coal. The average price of coal output in 1992, derived by dividing the value in the input–output table by the quantity of coal mined, is about 68 *yuan* per ton. This implies a tax on coal of about 7 per cent.

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Table 3. *Effects of a carbon tax on first year sectoral prices (percentage change from base case)*

Sector	*5% emissions reduction*	*10% emissions reduction*	*15% emissions reduction*
	%	%	%
1 Agriculture	0.08	0.16	0.25
2 Coal mining	6.05	12.88	20.63
3 Crude petroleum	1.02	2.16	3.43
4 Metal ore mining	0.20	0.41	0.64
5 Other non-metallic ore mining	0.17	0.35	0.53
6 Food manufacturing	0.05	0.10	0.16
7 Textiles	0.09	0.19	0.29
8 Apparel and leather products	0.08	0.16	0.25
9 Lumber and furniture manufacturing	0.15	0.32	0.50
10 Paper, cultural, and educational articles	0.11	0.24	0.37
11 Electric power	0.80	1.67	2.61
12 Petroleum refining	0.74	1.56	2.46
13 Chemicals	0.19	0.39	0.62
14 Building material	0.33	0.69	1.06
15 Primary metals	0.27	0.56	0.87
16 Metal products	0.17	0.34	0.54
17 Machinery	0.13	0.26	0.41
18 Transport equipment	0.14	0.28	0.43
19 Electric machinery and instruments	0.12	0.25	0.38
20 Electronic and communication equipment	0.10	0.21	0.33
21 Instruments and meters	0.11	0.23	0.36
22 Other industry	0.13	0.28	0.44
23 Construction	0.17	0.37	0.56
24 Transportation and communications	0.18	0.39	0.59
25 Commerce	0.10	0.19	0.30
26 Public utilities	0.13	0.28	0.43
27 Culture, education, health and research	0.11	0.23	0.35
28 Finance and insurance	0.07	0.15	0.22
29 Public administration	0.13	0.26	0.41

Source: Author's estimates.

real wage does not have a distortionary effect on hours worked. At the same time, because of the offsetting reductions in enterprise taxes, enterprise retained earnings are increased. Households do not receive a similar benefit from the reduction in the taxes of labor income because these taxes are negligible in the base year. As shown in figure 7, the increase in retained earnings is transferred into an increase in investment. Over time, this increased investment results in an increase in total output. This shows up within a few years in an increase in consumption over the baseline in all of the carbon tax simulations.

We can now look at the effects on the individual primary energy sectors (see tables 2, 3, and 4). After the imposition of the sectoral carbon tax on coal, in the first year of the 5 per cent reduction simulation the purchaser's (market) price of coal increases by 6.1 per cent. Because of its lower carbon content, the imposition of the sectoral carbon tax on oil causes the pur-

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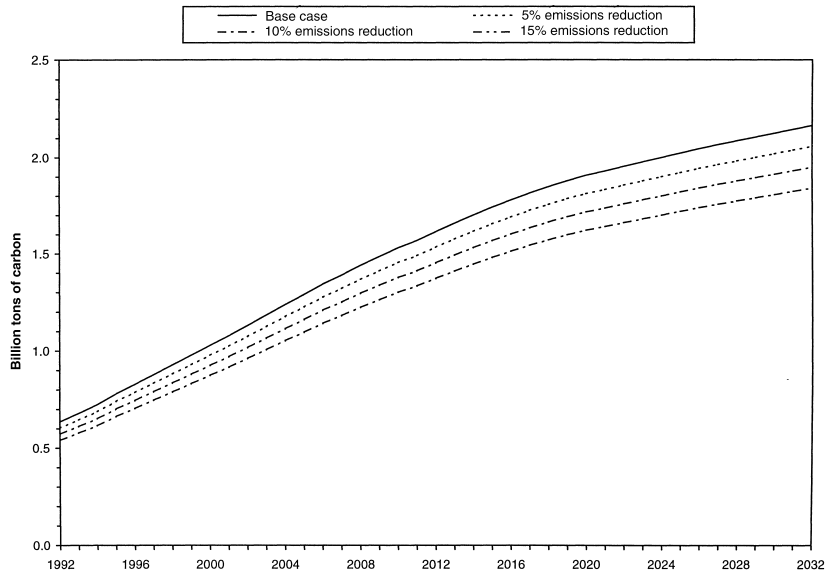


Figure 2. *Carbon emissions*

chaser's price of oil to rise by only 1.0 per cent. The increase in the price of coal results in a 6.0 per cent reduction in coal output. In the first year, oil sector output falls by 0.8 per cent while imports of oil and refined petroleum both fall by about 2 per cent. Overall, these changes lead to a fall in

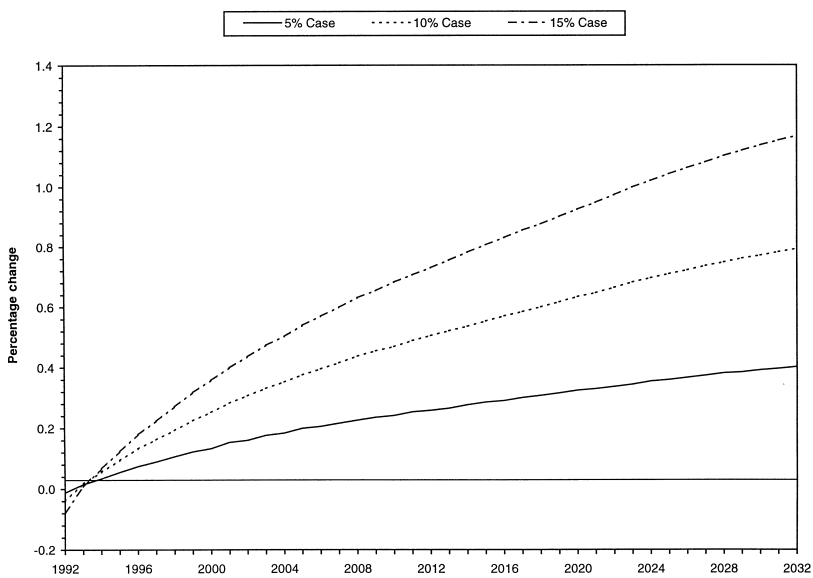


Figure 3. *Percentage change in GDP relative to base case*

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Table 4. *Effects of a carbon tax on first year sectoral output (percentage change from base case)*

Sector	*5% emissions reduction*	*10% emissions reduction*	*15% emissions reduction*
	%	%	%
1 Agriculture	−0.00	−0.00	−0.01
2 Coal mining	−5.97	−11.91	−17.82
3 Crude petroleum	−0.83	−1.75	−2.78
4 Metal ore mining	−0.08	−0.17	−0.27
5 Other non-metallic ore mining	−0.17	−0.36	−0.56
6 Food manufacturing	0.03	0.05	0.06
7 Textiles	0.01	0.02	0.01
8 Apparel and leather products	−0.01	−0.03	−0.06
9 Lumber and furniture manufacturing	−0.01	−0.03	−0.08
10 Paper, cultural, and educational articles	−0.01	−0.04	−0.07
11 Electric power	−0.99	−2.03	−3.13
12 Petroleum refining	−0.63	−1.31	−2.04
13 Chemicals	−0.10	−0.23	−0.37
14 Building material	−0.16	−0.35	−0.56
15 Primary metals	−0.18	−0.40	−0.63
16 Metal products	−0.08	−0.18	−0.29
17 Machinery	−0.01	−0.02	−0.05
18 Transport equipment	0.07	0.12	0.16
19 Electric machinery and instruments	−0.06	−0.13	−0.22
20 Electronic and communication equipment	0.01	0.01	−0.01
21 Instruments and meters	−0.05	−0.11	−0.18
22 Other industry	−0.13	−0.26	−0.41
23 Construction	0.18	0.36	0.52
24 Transportation and communications	−0.12	−0.25	−0.40
25 Commerce	−0.00	−0.01	−0.03
26 Public utilities	−0.08	−0.17	−0.27
27 Culture, education, health and research	−0.04	−0.09	−0.15
28 Finance and insurance	−0.02	−0.06	−0.09
29 Public administration	−0.01	−0.02	−0.04

Source: Author's estimates.

total primary energy use of 4.7 per cent, slightly less than the 5 per cent decline in total carbon emissions.[11]

Increasing the percentage reduction in carbon emissions requires a more than proportionate increase in sectoral carbon tax rates. For coal, the 5 per cent, 10 per cent, and 15 per cent reductions in carbon emissions require, respectively 6.1, 12.9, and 20.7 per cent increases in coal prices in the first year. Similar disproportionate increases in prices are required for oil. As shown in table 2, this holds true for coal and oil in both the first and thirtieth years of the simulations.

The effects on other sectors are predictable. Changes in purchaser's

[11] Total primary energy use is calculated as the simple sum of the standard coal equivalents of coal, oil, natural gas, and hydroelectricity.

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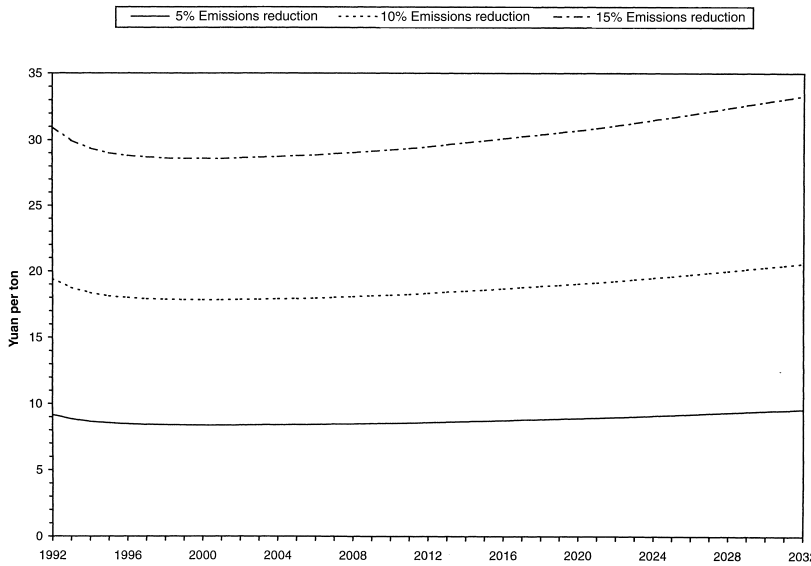


Figure 4. *Carbon taxes required to attain a given reduction in emissions*

(market) prices for the first year are given in table 3. Because of the rise in primary energy prices, sectors that use energy intensively experience proportionate price increases. For example in the 5 per cent reduction scenarios, the price of electricity increased by 0.8 per cent, building materials by 0.3 per cent, and primary metals by 0.3 per cent. Figures for

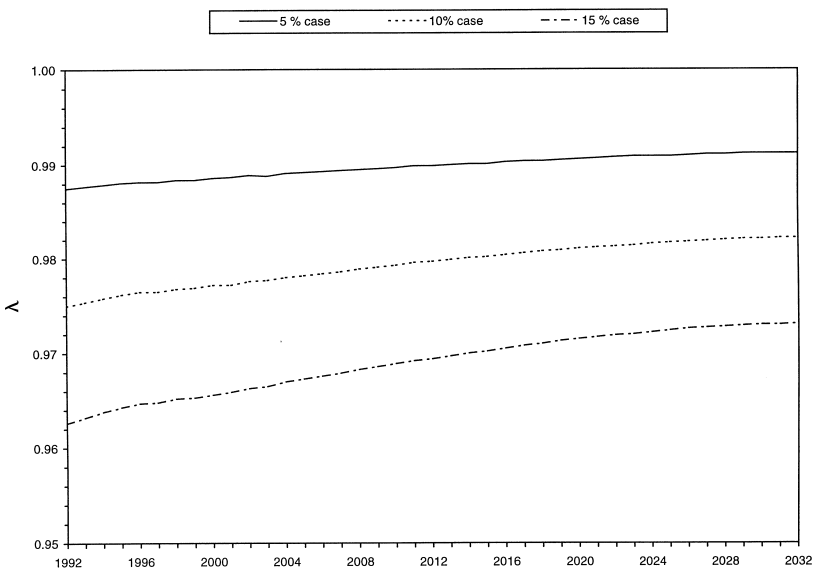


Figure 5. *Reduction in other taxes to offset carbon tax revenues*

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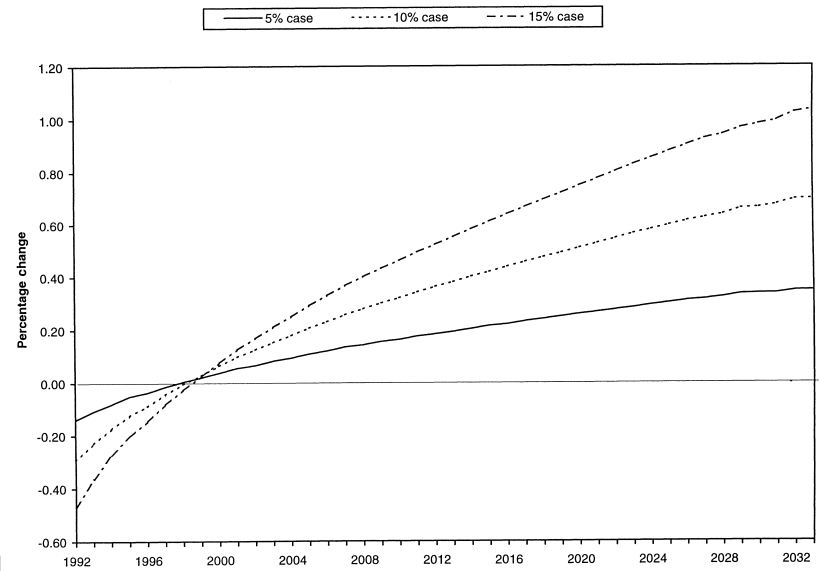


Figure 6. *Percentage change in consumption relative to base case*

changes in sectoral output are given in table 4. There are reductions in the output of electricity and refined petroleum. Agricultural output falls slightly because of the decline in demand due to the drop in real household income. At the same time, sectors that sell investment goods

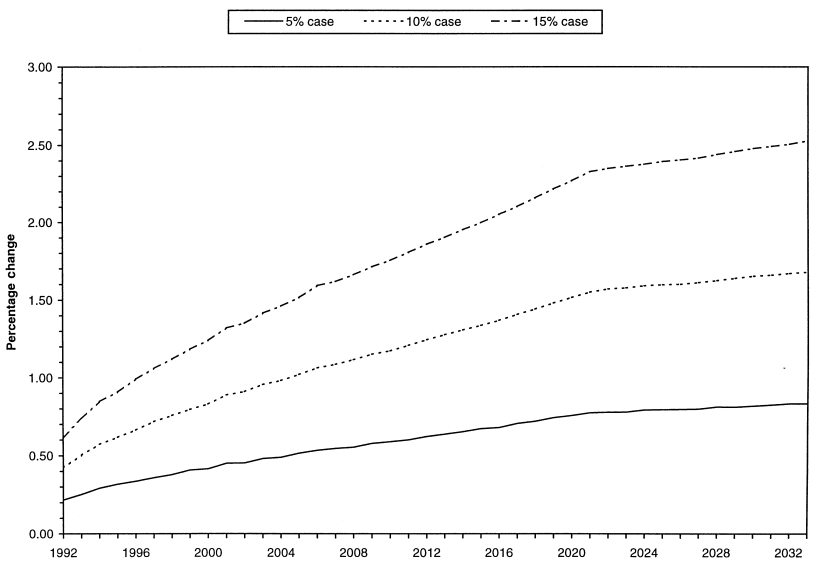


Figure 7. *Percentage change in investment relative to base case*

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(transport equipment and construction) experience increases in demand and output.

Over time, as the GDP and capital stock rise relative to the base case, higher demand for energy requires that the carbon tax rates be increased in order to continue to achieve the same proportionate reduction in emissions. In the 5 per cent carbon reduction case, this results in a 6.7 per cent increase in the market price of coal in the thirtieth year compared to the 6.1 per cent increase during the first year of the simulation (see table 2). The effect is reversed for oil because of the assumed availability of oil imports at the projected world price. The assumption that government spending is fixed in real terms, coupled with an increasing tax base, results in the revenue from the carbon tax falling as a share of total revenue over time. In the 5 per cent carbon reduction case, the share of revenue from the carbon tax falls from 1.2 per cent in the first year to 0.6 per cent in the thirtieth year. In the 15 per cent reduction case, the share falls from 3.6 to 1.9 per cent.

Two comments are in order on the pattern of carbon taxes over time in our model. The first concerns our assumptions about capital mobility. In the initial years of our simulations, the plan portion of capital dominates the total. The plan portion of capital is assumed to be immobile. Compared to models with completely mobile capital, this results in a much slower rate of substitution of capital for energy. Over time, the stock of mobile *market* capital rises in each industry and this results in more flexibility in later years. The second comment concerns the specification for the crude oil sector. The crude oil sector is one of two industries in the model with 'land' (oil reserves) as an input and the quantity of domestic reserves is assumed fixed. The domestic price of oil therefore rises relative to most other prices and imports of oil rise faster in the carbon tax simulations than in the base case. Alternative specifications, such as including exploration costs into our model or different assumptions about future world oil prices, could alter our results.

Finally, we should emphasize what our assumptions about the production functions and technical change imply. As discussed previously, the share coefficients are projected exogenously. This affects the level of energy use and has a major influence on the 'business as usual' baseline solution. However, the percentage change in energy use induced by the imposition of carbon taxes is determined by the elasticity of substitution between the various inputs. These elasticities are constant in our production functions and are therefore identical in both the base case and carbon tax simulations. The percentage change in input demands is not determined by the value of the share coefficients.[12]

[12] This comment applies to the other exogenous variables in the model as well. A different rate of technical progress, for example, would lead to a different path for the base case. However, the percentage change in variables (like GDP) resulting from the imposition of a carbon tax, would be only marginally affected. Assuming a more rapid rate of liberalization of the plan elements would have income, but not price effects.

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5. Conclusions

Our results paint a rather optimistic picture of the use of carbon taxes to induce a reduction CO_2 emissions in China. Although the imposition of a carbon tax results in a fall in consumption in the first few years of our simulations, in all of the emissions reduction scenarios analyzed, GDP rises above the baseline level after the first year. Within a few years, increases in investment also lead to increases in consumption above the baseline. Since we do not use an intertemporal utility function, we do not calculate discounted consumption. However, it would take an extremely high discount rate to produce a loss in the aggregate.

Recent work using analytical and computable general equilibrium models by Bovenberg and de Mooij (1994), Goulder (1995a), Parry (1995), Bovenberg and Goulder (1996), Böhringer, Pahlke, and Rutherford (1997), and others have case doubt on the likelihood of a 'double dividend' from environmental taxation. A review of this evolving literature is beyond the scope of this paper.[13] However, it is possible to point out a number of reasons why our results differ and in fact do not contradict those obtained in these studies. First, we should emphasize that our main result comes about because of the shift from consumption to investment brought about indirectly through the imposition of the carbon tax. Although GDP increases in every year after the first year, it drops below the baseline in the first year of all of our carbon tax simulations. Second, the most important element driving our results is our assumption that the labor supply in China is inelastic. With this specification, the fall in the real wage brought about by increases in goods prices has no distortionary effect on hours worked. The assumption of a positive labor supply elasticity is one of the key assumptions that leads to the rejection of the 'double dividend' hypothesis for developed country economies, but seems inappropriate in the context of China's transition economy.[14] Third, the fact that in China, taxes on labor are negligible means that households receive almost no benefit from the revenue neutral reduction in tax rates. This effect serves to further shift the burden of the carbon tax on to households. Fourth, most of the dynamic CGE models for developed economies have endogenously determined savings rates with perfect foresight, while the private savings rate in our model is exogenous (although not constant). Enterprise savings are affected by the revenue neutral reduction in the enterprise income tax, but there is no price effect in retained earnings. Hence the passive rise in investment. Finally, other distortions, like the two-tier price system and highly differentiated net output tax rates on intermediate and final goods, leave open the possibility for many welfare enhancing reforms, which may relate only coincidentally to environmental objectives.[15] Given that carbon

[13] A good overview of the 'double dividend' literature is given in Goulder (1995b).

[14] At this time we are aware of no study that has estimated a labor supply elasticity for China. However, we should note that allowing for an elastic labor supply in our model would require the inclusion of leisure in the welfare function. Given the development of labor markets in China and the high rate of unemployment, we do not believe that this would be a useful complication of the model.

[15] Some of the sectoral inequality in commodity tax rates was reduced following the taxation system reforms that took place at the beginning of 1994.

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taxes have the effect of reducing subsidies and raising prices for energy goods, our results are consistent with calls by the World Bank and others for China to increase efficiency by liberalizing energy markets.

Our results contrast with those of Zhang (1998a, 1998b) who found large decreases in output in his carbon tax simulations for China. Although Zhang also assumes an inelastic labor supply and an exogenous savings rate, there are a number of differences between the models which may account for the differing results. First, Zhang's model is based on data for 1987, while ours is based on data for 1992. As an example of the difference in base year data, Chinese imports of crude oil were negligible in 1987, but by 1992 had risen to 14 per cent of the value of domestic oil consumption. Second, the economy in Zhang's model is completely marketized, while we incorporate a number of features that reflect the mixture of plan and market that still exists in China. Third, Zhang's model has 10 sectors while ours has 29. The more refined classification in our model allows for a greater degree of substitution and hence reduces the losses from the imposition of carbon taxes.[16] Fourth, Zhang recycles only part of the carbon tax revenue while our simulations are revenue neutral. In addition, Zhang reduces only the indirect taxes, while we reduce all tax rates. These and other differences make a one-to-one comparison of the two models difficult if not impossible. [17]

While we believe that our model helps to point out how certain features of the Chinese economy may serve to ameliorate what might otherwise be negative consequences of the imposition of carbon taxes, a number of caveats are in order. First, the nature of the experiment is somewhat extreme. Consumers are not compensated while enterprises reap the full benefit of the revenue neutral reductions in tax rates. Also, given the underdevelopment of capital markets in China, one could certainly ask if the marginal efficiency of additional investment would be as high as is implied in our carbon tax simulations. Second, the cost of reducing emissions depends on the ability to substitute to alternative fuels or technologies. Our simple production functions are abstractions of much more complex current and future technologies. Although included implicitly in the production function for the electricity sector, a more detailed model might explicitly include hydro, nuclear, wind, and other non-carbon energy sources. In particular, our modeling of the electric power sector, as in most similar models, is very aggregated and may over or

[16] On the other hand, Zhang's model separates natural gas from the crude petroleum sector, allowing for an additional degree of fuel substitution after the imposition of a carbon tax.

[17] Zhang also makes some comparisons between the results of simulations with his China model and the China components of the Global 2100 (Manne, 1992) and GREEN (Oliveira-Martins *et al.,* 1993) multi-country models. Without revenue recycling, for a 20 per cent cut in carbon emissions, in the year 2010 there is a 1.52 per cent decline in GDP in Zhang's model, a 0.98 per cent decline in Global 2100, and a 0.25 per cent decline in GREEN. With partial revenue recycling, Zhang found a 1.47 per cent decline in GDP in the twentieth year. Unfortunately, a comparison of the same revenue recycling scenario is not available for the two multi-country models.

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understate the degree of substitution possible. Finally, we do not take into account the very substantial environmental benefits, aside from the decrease in greenhouse gas emissions, that would likely accompany reductions in CO_2 emissions in China. We hope to deal with these and other issues in future work.

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Appendix: Description of the model

The main features of the dynamic economy–energy–environment model for China are discussed in this appendix. Further details are given in Garbaccio, Ho, and Jorgenson (1997a). We describe the modeling of each of the main agents in the model in turn. Table A1 lists a number of parameters and variables which are referred to with some frequency. In general, a bar above a symbol indicates that it is a plan parameter or variable. A tilde indicates that a symbol refers to a market variable. Symbols without markings are, in general, total quantities or average prices. To reduce unnecessary notion, whenever possible, we drop the time subscript, t, from our equations.

A.1 Production

Each of the 29 industries is assumed to produce its output using a constant returns to scale technology. For each sector j this can be expressed as

$$QI_j = f(KD_j, LD_j, TD_j, A_{1j}, \ldots, A_{nj}, t), \tag{A1}$$

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Table A1. *Selected parameters and variables in the China model*

	Parameters
s_i^e	export subsidy rate on good i
t_i^c	carbon tax rate on good i
t^k	tax rate on capital income
t^L	tax rate on labor income
t_i^r	net import tariff rate on good i
t_i^t	net indirect tax (output tax less subsidy) rate on good i
t^x	unit tax per ton of carbon
	Endogenous variables
G_I	interest on government bonds paid to households
G_INV	investment through the government budget
G_IR	interest on government bonds paid to the rest of the world
$G_transfer$	government transfer payments to households
$P^{KD}{}_i$	rental price of market capital by sector
PE^*_i	export price in foreign current for good i
PI_i	producer price of good i
PI^t_i	purchaser price of good i including taxes
PL	average wage
PL_i	wage in sector i
PM_i	import price in domestic currency for good i
PM^*_i	import price in foreign currency for good i
PS_i	supply price of good i
PT_i	rental price of land of type i
QI_i	total output for sector i
QS_i	total supply for sector i
$r(B^*)$	payments by enterprises to the rest of the world
$R_transfer$	transfers to households from the rest of the world

where KD_j, LD_j, TD_j, and A_{ij} are capital, labor, land, and intermediate inputs, respectively.[18] In sectors for which both plan and market allocation exists, output is made up of two components, the plan quota output ($\overline{QI}_j$) and the output sold on the market ($\tilde{QI}_j$). The plan quota output is sold at the state-set price ($\overline{PI}_j$) while the output in excess of the quote is sold at the market price ($\tilde{PI}_j$).

A more detailed discussion of how this plan-market formulation is different from standard market economy models is given in Garbaccio, Ho, and Jorgenson (1997b). In summary, if the constraints are not binding, then the 'two-tier plan/market' economy operates at the margin as a market economy with lump sum transfers between agents. The return to the owners of fixed capital in sector j is

$$profit_j = \bar{PI}_j\,\bar{QI}_j + \tilde{PI}_j\,\tilde{QI}_j - \tilde{PI}^{KD}{}_j\,\tilde{KD}_j - PL_j\,LD_j - PT_j\,TD_j - \sum_i \bar{PS}_i\,\bar{A}_{ij} - \sum_i \tilde{PS}_i\,\tilde{A}_{ij}. \quad \text{(A2)}$$

[18] QI_j denotes the quantity of industry j's output. This is to distinguish it from QC_j, the quantity of commodity j. In the actual model each industry may produce more than one commodity and each commodity may be produced by more than one industry. In the language of the input–output tables, we make use of both the USE and MAKE matrices. For ease of exposition we ignore this distinction here.

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For each industry, given the capital stock $\bar{K}_j$ and prices, the first-order conditions from maximizing equation A2, subject to equation A1, determine the market and total input demands.

Given the lack of a consistent time series data set, in this version of the model, we use Cobb–Douglas production functions. Equation A1 for the output of industry j at time t then becomes

$$QI_{jt} = g(t)KD_{jt}^{\alpha_{Kj}}LD_{jt}^{\alpha_{Lj}}TD_{jt}^{\alpha_{Tj}}E_{jt}^{\alpha_{Ej}}M_{jt}^{\alpha_{Mj}}, \text{ where}$$

$$\log E_{jt} = \sum_k \alpha_{kj}^E \log A_{kjt} \text{ and } k = \text{coal, oil, electricity, and refined petroleum,}$$

$$\log M_{jt} = \sum_k \alpha_{kj}^M \log A_{kjt} \text{ and } k = \text{non-energy intermediate goods.} \quad \text{(A3)}$$

Here α_{Ej} is the cost share of aggregate energy inputs in the production process and α_{kj}^E is the share of energy of type k within the aggregate energy input. Similarly, α_{Mj} is the cost share of aggregate non-energy intermediate inputs and α_{kj}^M is the share of intermediate non-energy input of type k within the aggregate non-energy intermediate input.

To allow for biased technical change, the α_{Ej} coefficients are indexed by time and are updated exogenously. We set α_{Ej} to fall gradually over the next 40 years while the labor coefficient, α_{Lj}, rises correspondingly. The composition of the aggregate energy input (i.e., the coefficients α_{kj}^E) are also allowed to change over time. These coefficients are adjusted gradually so that they come close to resembling the US use patterns of 1992. The exception is that the Chinese coefficients for coal for most industries will not vanish as they have in the US.[19] The coefficient $g(t)$ in equation A3 represents technical progress and the change in $g(t)$ is determined through an exponential function ($\dot{g}_j(t) = A_j \exp(-\mu_j t)$). This implies technical change that is rapid initially, but gradually declines toward zero. The price to buyers of this output includes the indirect tax on output and the carbon tax

$$PI_i^t = (1 + t_i^t)PI_i + t_i^c. \quad \text{(A4)}$$

A.2 Households

The household sector derives utility from the consumption of commodities, is assumed to supply labor inelastically, and owns a share of the capital stock. It also receives income transfers and interest on its holdings of public debt. Private income after taxes and the payment of various non-tax fees (*FEE*), Y^p, can then be written as

$$Y^p = YL + DIV + G_I + G_transfer + R_transfer - \text{FEE}, \quad \text{(A5)}$$

[19] We have chosen to use US patterns in our projections of these exogenous parameters because they seem to be a reasonable anchor. While it is unlikely that China's economy in 2032 will mirror the US economy of 1992, it is also unlikely to closely resemble any other economy. Other projections, such as those by the World Bank (1994), use the input–output tables of developed countries including the US. We have considered making extrapolations based on recent Chinese input–output tables, but given the short sample period and magnitude of the changes in recent years, this did not seem sensible.

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where YL denotes labor income from supplying LS units of effective labor, less income taxes. YL is equal to

$$YL = (1 - t^L)PL\ LS. \tag{A6}$$

The relationship between labor demand and supply is given in equation A31 below. LS is a function of the working age population, average annual hours, and an index of labor quality

$$LS_t = POP^w_t\, hr_t\, q^L_t. \tag{A7}$$

Household income is allocated between consumption (VCC_t) and savings. In this version of the model we use a simple Solow growth model formulation with an exogenous savings rate (s_t) to determine private savings (S^p_t)

$$S^p_t = s_t Y^p_t = Y^p_t - VCC_t. \tag{A8}$$

Household utility is a function of the consumption of goods such that

$$U_t = U(C_{1t},...,C_{nt}) = \sum_i \alpha^C_{it} \log C_{it}. \tag{A9}$$

Assuming that the plan constraints are not binding, then as in the producer problem above, given market prices and total expenditures, the first-order conditions derived from equation (A9) determine household demand for commodities, C_i, where $C_i = \bar{C}_i + \tilde{C}_i$. Here $\bar{C}_i$ and $\tilde{C}_i$ are household purchases of commodities at state-set and market prices. The household budget can be written as

$$VCC = \sum_i (\tilde{P}S_i\, \tilde{C}i + \bar{P}S_i\, \bar{C}_i). \tag{A10}$$

We use a Cobb–Douglas utility function because we currently lack the disaggregated data to estimate an income elastic functional form. However, one would except demand patterns to change with rising incomes and this is implemented by allowing the α^C_{it} coefficients to change over time. These future demand patterns are projected using the US use patterns of 1992.

A.3 Government and taxes

In the model, the government has two major roles. First, it sets plan prices and output quotas and allocates investment funds. Second, it imposes taxes, purchases commodities, and redistributes resources. Public revenue comes from direct taxes on capital and labor, indirect taxes on output, tariffs on imports, the carbon tax, and other non-tax receipts

$$\begin{aligned} Rev = \sum_j t^k\,(P^{KD}_j - D_j) + t^L \sum_j PL_j\, LD_j + \sum_j t^t_j\, PI_j\, QI_j + \\ \sum_i t^r_i\, PM^*_i\, M_i + \sum_i t^c_i\,(QI_i - X_i + M_i) + FEE, \end{aligned} \tag{A11}$$

where D_j is the depreciation allowance and X_i and M_i are the exports and imports of good i. The carbon tax per unit of fuel i is

$$t^c_i = t^x\, \theta_i, \tag{A12}$$

where t^x is the unit carbon tax calculated per ton of carbon and θ_i is the emissions coefficient for each fuel type i.

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Total government expenditure is the sum of commodity purchases and other payments

$$Expend = VGG + G_INV + \sum s_i^e PI_i X_i + G_I + G_IR + G_transfer \quad \text{(A13)}$$

Government purchases of specific commodities are allocated as shares of the total value of government expenditures, *VGG*. For good *i*

$$PS_i\, G_i = \alpha_i^G\, VGG. \quad \text{(A14)}$$

We construct a price index for government purchases as $\log PGG = \sum_i \alpha_i^G \log PS_i$. The real quantity of government purchases is then

$$GG = \frac{VGG}{PGG}. \quad \text{(A15)}$$

The difference between revenue and expenditure is the deficit, ΔG, which is covered by increases in the public debt, both domestic (B) and foreign (B^{G*})

$$\Delta G_t = Expend_t - Rev_t, \quad \text{(A16)}$$

$$B_t + B_t^{G*} + B_{t-1} - B_{t-1}^{G*} - \Delta G_t. \quad \text{(A17)}$$

The deficit and interest payments are set exogenously and equation (A16) is satisfied by making the level of total government expenditure on goods, *VGG*, endogenous.

A.4 Capital, investment, and the financial system

We model the structure of investment in a fairly simple manner. In the Chinese economy, some state-owned enterprises receive investment funds directly from the state budget and are allocated credit on favorable terms through the state-owned banking system. Non-state enterprises get a negligible share of state investment funds and must borrow at what are close to competitive interest rates. There is also a small but growing stock market that provides an alternative channel for private savings. We abstract from these features and define the capital stock in each sector *j* as the sum of two parts, which we call plan and market capital

$$K_{jt} = \bar{K}_{jt} + \tilde{K}_{jt}. \quad \text{(A18)}$$

The plan portion evolves with plan investment and depreciation

$$\bar{K}_{jt} = (1-\delta)\bar{K}_{jt-1} + \bar{I}_{jt},\ t = 1,2, \ldots, T. \quad \text{(A19)}$$

In this formulation, $\bar{K}_{j0}$ is the capital stock in sector *j* at the beginning of the simulation. This portion is assumed to be immobile across sectors. Over time, with depreciation and limited government investment, it will decline in importance. Each sector may also 'rent' capital from the total stock of market capital, $\tilde{K}_t$

$$\tilde{K}_t = \sum_j \tilde{K}_{jt}, \text{ where } \tilde{K}_{jt} > 0. \quad \text{(A20)}$$

The allocation of market capital to individual sectors, $\tilde{K}_{jt}$, is based on sectoral rates of return. As in equation (A2), the rental price of market capital by sector is $\tilde{P}_j^{KD}$ The supply of $\tilde{K}_{jt}$, subject to equation (A20), is written as a

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translog function of all of the market capital rental prices, $\tilde{K}_{jt} = K_j(\tilde{P}_1^{KD},..., \tilde{P}_n^{KD})$.

In two sectors, agriculture and crude petroleum, 'land' is a factor of production. We have assumed that agricultural land and oil fields are supplied inelastically, abstracting from the complex property rights issues regarding land in China. After taxes, income derived from plan capital, market capital, and land is either kept as retained earnings by the enterprises, distributed as dividends, or paid to foreign owners

$$\sum_j profits_j + \sum_j \tilde{P}_j^{KD}\tilde{K}_j + \sum_j PT_jT_j = tax(k) + RE_DIV_r(B^*), \tag{A21}$$

where *tax(k)* is total direct taxes on capital (the first term on the right-hand side of equation (A11).[20]

As discussed below, total investment in the model is determined by savings. This total, *VII*, is then distributed to the individual investment goods sectors through fixed shares, α_{it}^I

$$PS_{it}I_{it} = \alpha_{it}^I VII_t. \tag{A22}$$

Like the α_{it}^C coefficients in the consumption function, the investment coefficients are indexed by time and projected using US patterns for 1992. A portion of sectoral investment, $\bar{I}_t$, is allocated directly by the government, while the remainder, $\tilde{I}_t$, is allocated through other channels.[21] The total, I_t, can be written as

$$I_t = \tilde{I}_t + \bar{I}_t = I_{1t}^{\alpha_1^I} I_{2t}^{\alpha_2^I}...I_n^{\alpha_n^I} \tag{A23}$$

As in equation (A19) for the plan capital stock, the market capital stock, $\tilde{K}_{jt}$, evolves with new market investment

$$\tilde{K}_{jt} = (1-\delta)\tilde{K}_{jt-1} + \tilde{I}_{jt}. \tag{A24}$$

A.5 The foreign sector

Trade flows are modeled using the method followed in most single-country models. Imports are considered to be imperfect substitutes for domestic commodities and exports face a downward-sloping demand curve. We write the total supply of commodity *i* as a CES function of the domestic (QI_i) and imported good (M_i)

$$QS_i = A_0[\alpha^d QI_i^{\rho} + \alpha^m M_i^{\rho}]^{1/\rho}, \tag{A25}$$

where $PS_iQS_i = PI_i^tQI_i + PM_iM_i$ is the value of total supply. The purchaser's price for domestic goods, PI_i^t, is discussed in the producer section above. The price of imports to buyers is the foreign price plus tariffs (less export subsidies), multiplied by a world relative price, *e*

$$PM_i = e(1 + t_i^r)PM_i^*. \tag{A26}$$

[20] In China, most of the 'dividends' are actually income due to agricultural land.

[21] It should be noted that the industries in the Chinese accounts include many sectors that would be considered public goods in other countries. Examples include local transit, education, and health.

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Exports are written as a simple function of the domestic price relative to world prices adjusted for export subsidies (s^e_{it})

$$X_{it} = EX_{it}\left(\frac{\tilde{P}I_{it}}{e_t(1 + s^e_{it} + PE^*_{it}}\right)^{\eta_i}, \tag{A27}$$

where EX_{it} is base case exports that are projected exogenously.

The current account balance is equal to exports minus imports, less net factor payments, plus transfers

$$CA = \sum_i \frac{PI_iX_i}{(1 + s^e_i)} - \sum_i PM_iM_i - r(B^*) - G_IR + R_transfer, \tag{A28}$$

Like the government deficits, the current account balances are set exogenously and accumulate into stocks of net foreign debt, both private (B^*_t) and public $B^{G^*}_t$)

$$B^*_t + B^{G^*}_t = B^*_{t-1} + B^{G^*}_{t-1} - CA_t. \tag{A29}$$

A.6 Markets

The economy is in equilibrium in period t when the market prices clear the markets for the 29 commodities and the two factors. The supply of commodity I must satisfy the total of intermediate and final demands

$$QS_i = \sum_j A_{ij} + C_i + I_i + G_i + X_i,\ i = 1, 2, ..., 29. \tag{A30}$$

For the labor market, we assume that labor is perfectly mobile across sectors so there is one average market wage which balances supply and demand. As is standard in models of this type, we reconcile this wage with the observed spread of sectoral wages using wage distribution coefficients, ψ^L_{jt}. Each industry pays $PL_{jt} = \psi^L_{jt}PL_t$ for a unit of labor. The labor market equilibrium is then given as

$$\sum_j \psi^L_{jt}\, LD_{jt} = LS_t. \tag{A31}$$

For the non-plan portion of the capital market, adjustments in the market price of capital, $\tilde{P}^{KD}_j$, clears the market in sector j

$$KD_{jt} = \psi^K_{jt}K_{jt}, \tag{A32}$$

where ψ^K_{jt} converts the units of capital stock into the units used in the production function. The rental price PT_j adjusts to clear the market for 'land'

$$TD_j = T_j, \text{ where } j = \text{'agriculture' and 'petroleum extraction'}. \tag{A33}$$

In this model without foresight, investment equals savings. There is no market where the supply of savings is equated to the demand for investment. The sum of savings by households, businesses (as retained earnings), and the government is equal to the total value of investment plus the budget deficit and net foreign investment

$$S^p + RE + G_INV = VII + \Delta G + CA. \tag{A34}$$

The budget deficit and current account balance are fixed exogenously in each period. The world relative price (e) adjusts to hold the current account balance as its exogenously determined level.

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