A Dynamic Economy-Energy-Environment Model of China
Version 2

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1 Introduction

The sheer size and rapid growth of the Chinese economy have made it the center of much attention. The attention ranges from those concerned about global climate change to those worried about the U.S.-China bilateral trade deficit. Much effort has been expended on trying to understand and predict the future of the Chinese economy. The uncertainty surrounding expected further reform have made the work of advising policy makers even more difficult.

We have previously constructed a model of China (Garbaccio, Ho and Jorgenson 1996) to help in understanding the workings of the economy, to identify the main forces driving growth, and to forecast some likely trajectories. This document describes a major revision to that model. The main objectives remain – the study of how tax and environmental policy changes might affect growth, energy use, and pollution. In this version of the model we study both global and local pollution, this includes particulate and sulphur dioxide pollution that directly affect human health.

Many of the recent studies of economic-environmental interaction concern market economies. However, even after the reforms of the past twenty-two years, China’s economy still has a substantial plan component, especially in the capital markets. Our model takes account of these plan/market features explicitly, allowing for policy control over a portion of output, prices, and investment.

Many of the current numerical models of China are static in nature, focusing on the long run effects of economic policies. In contrast, our model is dynamic, calculating an equilibrium for each year thus distinguishing the immediate impact from the long run effects. In our model we make explicit our assumptions of population growth, the changing composition of the population, technological change, and changes in external factors like world oil prices.

As part of our work we have constructed a data set that includes time series for many variables which will be used to estimate the parameters of the model. Complete and consistent economic data for China are not available at present and we have tried to fill in some of the more important missing pieces such as valuation of land inputs. We include a fairly complete social accounting matrix for 1995 based on the official input-output table.

Simulation results are reported in separate papers. This document gives a detailed description of the model and data construction.
2 Overview of Model

Given the complexity of multisector models we shall first give a summary of the main features of our model in this Overview section.

- $DE^3$ is a multisector model with 30 industries identified. We distinguish between industries and commodities. An industry may produce more than one commodity and a commodity may be produced by more than one industry. (I.e., both USE and MAKE input-output tables are used.)

- Each cell in the input-output table has two components: a plan component and a market component. The plan quantities and prices are set exogenously and may change over time according to one’s forecast of the plan.

- Output is produced using constant returns to scale technology. There is technical progress over time and the share of energy in total costs is also allowed to change (biased technical change).

- The Armington assumption. Domestic output is combined with imports to produce a composite supply using a CES function. Exports are price sensitive. The current account balance and world commodity prices are set exogenously.

- The market component of the labor force is mobile across sectors. Capital has both fixed and mobile components.

- Growth is driven by an aggregate household with an exogenously set savings rate as in the Solow growth model. This savings rate may change over time.

- Commodity demand by the household is specified as a Cobb-Douglas utility function.

- The public deficit is set exogenously, tax rates are fixed, and expenditures are endogenous.

- Temporal accounting is observed; government deficits accumulate into a stock of public debt, current account deficits accumulate into a stock of foreign debt, and investment cumulate into capital.

- Agriculture, crude petroleum and gas extraction have land as fixed inputs. All sectors have reproducible capital as an input.
Time series projections are made of exogenous variables, including population (total and age composition), public and current account deficits, world commodity prices, plan quantities and prices, and an index of technology.

The flows in the economy are illustrated in Figures 1a and 1b and a social accounting matrix (SAM) for 1995 is given in Figure 2.¹

Notation.
A complete glossary is given in section 12. Prices have variable names beginning with P, most quantities with Q, and values with V; plan variables have bars over them, market variables have tildes, and average prices are unmarked. In general, the \( i \) subscript refers to commodities while the \( j \) subscript refers to industries. Tax variables begin with \( t \), government expenditure items begin with \( G \), and variables for the rest-of-the-world are marked with an asterisk. Parameters and coefficients are represented by Greek letters.

¹All diagrams and tables are at the end of the paper.
3 Production

The model identifies 30 industries, each producing output using capital, labor, intermediate inputs, and for certain sectors, land. The sectors are defined in Table 1. The technology is represented by a constant returns to scale Cobb-Douglas function with a nested structure for intermediate inputs. Technical progress is allowed and the level of technology is indexed by time $t$. The output for industry $j$ may be represented as:

$$QI_{jt} = QI^j(TD_j, KD_j, LD_j, QP^{jE}, QP^{jM}, t)$$  \hspace{1cm} (1)

$TD, KD, LD$ denote the demand for land, capital, and labor. The intermediate input bundles are aggregated over the energy and non-energy inputs, $QP_i$:

- $QP^{jE} = QP^E(QP_2^j, QP_3^j, QP_4^j, QP_{12}^j, QP_{13}^j)$  \hspace{1cm} Energy input aggregate
- $QP^{jM} = QP^M(QP_1^j, QP_5^j, \ldots QP_{11}^j, QP_{14}^j, \ldots QP_{30}^j)$  \hspace{1cm} Material input aggregate

We shall use the following index sets for industries and commodities:

- $I_{IND} = \{1, 2, \ldots, 30\}$
- $I_{COM} = \{1, 2, \ldots, 30\}$

We find it convenient to also work with the price dual functions. The industry output price corresponding to the above quantity is:

$$PO_{jt} = f(PT_j, PKD_j, PLD_j, PP^{jE}, PP^{jM}, t) \quad j \in I_{IND}$$  \hspace{1cm} (2)

where $PT$, $PKD$, and $PLD$ are the prices of land, capital and labor input respectively. The prices for the intermediate input bundles are functions of the individual commodity prices, $PS_i$:

- $PP^{jE} = f(PS_2, PS_3, PS_4, PS_{12}, PS_{13})$
- $PP^{jM} = f(PS_1, PS_5, \ldots PS_{30})$

The S in $PS$ denotes the supply price of the commodities, this is explained below in Section 7.

The industry output price $PO$ is the price received by the sellers. The industry output price paid by buyers includes various subsidies and taxes (both ad valorem and unit taxes) that are explained below (eqn 32):

$$PI_j = (1 + tt^j_j)PO_j \quad j \in I_{IND}$$  \hspace{1cm} (3)

Output is divided into two components, a plan quantity, $\overline{QI}_j$, and a market quantity $\widetilde{QI}_j$. The plan quantity is the amount that the government requires enterprises to deliver at a state-set price $\overline{P}_j$. The market component is sold at the market price $\widetilde{PO}_j$. 

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Inputs are also divided into two parts. In the labor market, the tradition of the “iron rice bowl” is well known. Workers in state-owned enterprises generally expected to keep their jobs for life with little possibility of being laid off or fired. We represent such tenured workers as $\bar{LD}$ while the labor hired in the spot market is denoted $\bar{LD}$. Part of the intermediate input requirements are also supplied by the plan. In particular, some manufacturing enterprises may obtain raw materials at lower state-set prices. Plan inputs are denoted as $\bar{QP}_i$ with prices $\bar{PP}_i$. We assume that for a single commodity, the plan price is the same for all purchasers.

The other inputs are capital and land, which are also divided into government controlled and market components. The pricing of these inputs is discussed in detail below. For now let the fixed capital in sector $j$ be $\bar{K}_j$ and the additional capital rented through the market be $\bar{KD}_j$. Putting all these components together we have:

\begin{align*}
QI_j &= QI_j + \bar{QI}_j \\
LD_j &= LD_j + \bar{LD}_j \\
QP_i^j &= QP_i^j + \bar{QP}_i^j & \text{if } i \in ICOM \\
PO_jQI_j &= PO_jQI_j + \bar{PO}_j\bar{QI}_j
\end{align*}

A word about the agricultural and real estate sectors is in order here. Of the 30 sectors agriculture is the biggest employer. With the reforms of the late 1970s this sector has seen the most change, however, it is still characterized by features that are very different from those in market economies. While agricultural households now have many rights over the land they farm, strictly speaking, no formal land market exists. We shall not be aiming for a sophisticated description of the agricultural sector here and simply consider all agricultural labor as market labor. However, we do create a new accounting entity that is not in the official income accounts: land. This land is conceptually owned by the households and is supplied competitively. Agricultural firms rent land at a price that is equal to its marginal product in equilibrium. In reality, the informal property rights structure make the owner and renter one and same person, but this separation is a useful and important way of characterizing the economic decisions of the farmers and to model the further liberalization of the rural sector.

For the real estate sector, unfortunately, we do not yet have the data that would allow even a crude estimation of the value of land and the rental value due to land. We therefore have to ignore this and attribute all of property income to capital. Again we should note that the property rights to housing in China is complex and in a state of transition. This should be more carefully modeled.
in future versions of the model.

Since 1995 a major new tax, the value added tax (VAT), has been imposed on all the industrial sectors as well as the commerce sector. The sectors not subject to the VAT are the service sectors and agriculture. The complication in the Chinese situation is that the VAT rate is not evenly applied to all commodities. If it were applied at a common rate to all commodities then the VAT is equivalent to a tax on final demand. That is, only final purchasers of commodity \( i \) pay the tax, intermediate purchasers do not, and the cost functions above may be used directly. This is the approach taken, for example, in the GEM-E3 model of Europe (Capros et al. 1997). Here we take a direct approach and apply the tax on the producers.\(^2\) With this VAT, given the fixed capital \( K_j \), the enterprise objective is to maximize:

\[
\text{profit}(K_j) = PO_j QI_j + PKD_j^s KDJ_j - PL_j^s LD_j - PL_j^s LD_j
\]

\[
-PT_j^s TD_j - \sum_i PS_i^j QP_i^j - \sum_i TP_i^j QP_i^j
\]

\[
-tv_j (PO_j QI_j + P_j QI_j - \sum_i PS_i^j QP_i^j - \sum_i TP_i^j QP_i^j)
\]

s.t. \( QI_j + QI_j = QI(TD_j, K + KDJ_j, LD_j, LD_j, QP_i^j + QP_i^j, ..., t) \) (9)

where we have added the superscript \( s \) on the factor prices to denote the price received by the factor supplier. The first order conditions are:

\[
PT_j^s = (1 - tv_j) PO_j MP_T(TD_j, KDJ_j, LD_j, LD_j, QP_i^j + QP_i^j, ..., t)
\]

\[
PKD_j^s = (1 - tv_j) PO_j MP_K(TD_j, KDJ_j, LD_j, LD_j, QP_i^j + QP_i^j, ..., t)
\]

\[
PL_j^s = (1 - tv_j) PO_j MP_L(TD_j, KDJ_j, LD_j, LD_j, QP_i^j + QP_i^j, ..., t)
\]

\[
PS_i = PO_j MP_i(TD_j, KDJ_j, LD_j + LD_j, QP_i^j + QP_i^j, ..., t) \quad i \in I_{COM}
\]

where \( MP_\bullet \) denotes the marginal products of the respective inputs. These foc’s give the demands for inputs given prices and output levels. Expressing in terms of factor prices to the seller, we get the familiar foc’s:

\(^2\)This is similar to the approach in Zhai and Li (2000).
With Cobb-Douglas production functions, eq. (1) is written as (suppressing the $j$ index):

$$\log(\tilde{Q}_I^j + \tilde{Q}_I) = \alpha_{Tt} \log TD_j + \alpha_{Kt} \log(\tilde{K} + \tilde{KD}_j) + \alpha_{Lt} \log(\tilde{L} + \tilde{LD})$$

$$+ \alpha_{Et} \log QP_{Ei} + \alpha_{Mt} \log QP_{Mi} + \alpha_0 + \alpha g(t)$$

$$g(t) = \alpha_{Oj} + \alpha_{ij}^t \exp\left(-\mu^i(t - \tau^j)\right) / \mu^j$$

At present, we have chosen the technical progress term, $g(t)$, to be of the exponential form, $\frac{dp}{dt} = \alpha_1 \exp(\mu t)$, that is, to have rapid productivity improvements in the beginning but to fall to zero in the long run (beyond the 40-60 years that we are usually concerned with). We also allow for non-neutral technical change, that is, production over time may use different ratios of the various inputs separately from price effects. In the Cobb-Douglas case, this means that the $\alpha$’s at the top tier are allowed to trend through time. We have experimented with various methods for projecting these input shares and have chosen to let them gradually resemble the production structure of the US as described in the US 1982 input output table. (See Section 11 on Parameters.)

The f.o.c.’s at the top tier for the Cobb-Douglas formulation gives the value shares for the inputs calculated at market prices:

$$SP^{j\text{TOP}} = \begin{bmatrix} PT_j TD_j / \tilde{P}O_j QI_j \\ PKD_j KD_j / \tilde{P}O_j QI_j \\ \tilde{P}L_j LD_j / \tilde{P}O_j QI_j \\ PP^E QP^E / \tilde{P}O_j QI_j \\ PP^M QP^M / \tilde{P}O_j QI_j \end{bmatrix} = \begin{bmatrix} \alpha_{Tt} \\ \alpha_{Kt} \\ \alpha_{Lt} \\ \alpha_{Et} \\ \alpha_{Mt} \end{bmatrix}$$

See Jorgenson, Gollop and Fraumeni (1987) for a discussion of biased technical progress and methods to estimate it for U.S. data.
For the bottom tiers we have similarly:

\[ SP^E = \begin{bmatrix} \widetilde{PS}_3QP_2/\widetilde{PP}^EQP^E \\ \vdots \\ \widetilde{PS}_{13}QP_{13}/\widetilde{PP}^EQP^E \end{bmatrix} = \alpha_i^E \quad \widetilde{PS}_iQP_i/\widetilde{POI}_i = \alpha_i^E \alpha_{Et} \quad (22) \]

\[ SP^M = \begin{bmatrix} \widetilde{PS}_5QP_5/\widetilde{PP}^MQ^M \\ \vdots \\ \widetilde{PS}_{30}QP_{30}/\widetilde{PP}^MQ^M \end{bmatrix} = \alpha_i^M \quad \widetilde{PS}_iQP_i/\widetilde{POI}_i = \alpha_i^M \alpha_{Mt} \quad (23) \]

Since we impose constant returns to scale we have zero profits when evaluated at market prices:

\[ \widetilde{PO}_jQI_j = PT_jTD_j + \widetilde{PKD}_jKD_j + \widetilde{PL}_jLD_j + \widetilde{PP}^E_jQP^E_j + \widetilde{PP}^M_jQP^M_j \quad (24) \]

\[ = PT_jTD_j + \widetilde{PKD}_jKD_j + \widetilde{PL}_jLD_j + \sum_i \widetilde{PS}_iQP_i \quad (25) \]

The implicit transfers to and from the enterprise due to the lower state-set prices are:

\[ TR^L_j = (\widetilde{PL}_j - \mathcal{P}_j)L_j \quad (26) \]

\[ TR^P_j = \sum_i (\widetilde{PS}_i - \mathcal{P}_j)QP_i^j \quad (27) \]

\[ TR^O_j = (\widetilde{PO}_j - \mathcal{P}_j)QO_j \quad (28) \]

In a completely deregulated market the gross profit for sector \( j \) is:

\[ \Pi(\widetilde{K}_j) = \widetilde{PO}_jQI_j - \widetilde{PKD}_j\widetilde{KD}_j - \widetilde{PL}_jLD_j - \sum_i \widetilde{PS}_iQP_i^j \quad (29) \]

The difference between this and the actual profit in eq. (8) is the transfers:

\[ profit(\widetilde{K}_j) = \Pi(\widetilde{K}_j) - TR^O + TR^L + TR^P \quad (30) \]

The model allows various taxes to be placed on output, including those that are not in use at present but may be imposed in the future as pollution taxes. Repeating eq. (3) from above for market prices:

\[ \widetilde{PI}_j = (1+t_t - ts_j + tx^u_j)\widetilde{PO}_j + tx^u_j + tp^p_j \quad j \in I_{IND} \quad (31) \]
where $tt_j$ and $ts_j$ are the sales tax and sales subsidy for the market portion of output, $tx^u_j$ is the ad valorem externality tax, $tx^u_j$ is the unit externality tax, and $tp^p_j$ are pollution charges for waste water and other emissions. The externality taxes are intended to implement carbon taxes, i.e. those based on the amount of $CO_2$ produced in the use of commodity $j$. The pollution charges are those imposed for the production of commodity $j$, and may be changed when methods of producing $j$ are changed. Thus $tx$ is also imposed on imports while $tp$ is imposed of production, whether it is for domestic use or exported. After summing all these taxes, the full tax on $j$ is:

$$tt^f_j = tt_j - ts_j + tx^u_j + \frac{tx^u_j}{PO_j} + \frac{tp^p_j}{PO_j}$$

(32)

We define the following vectors of the value of output for use later:

$$\vec{VQI} \equiv (PO_1QI_1, ..., PO_{30}QI_{30})'$$

(33)

$$\vec{VQI}^u \equiv (\vec{P}I_1QI_1, ..., \vec{P}I_{30}QI_{30})'$$

(34)

$$= \text{Diag}(t + tt^f)\vec{VQI}$$

(35)

Our model distinguishes between industries and commodities, so that each industry may produce more than one commodity, and each commodity may be produced by more than one industry. This is in line with the way input-output data are actually collected, i.e. utilizing both USE and MAKE tables. The $j$th column of the USE table gives the inputs of industry $j$, the $i$th column of the MAKE matrix gives the sources of commodity $i$. The USE matrix is determined by the input demand equations (20-22) above. For the MAKE matrix we assume fixed shares, i.e. each commodity $i$ is has a fixed composition with $M_{ij} \times 100\%$ coming from industry $j$. Denoting the quantity and price of commodity $i$ by $QC_i$ and $PC_i$ we have:

$$\vec{PC} = M'\vec{P}I$$

(36)

$$\vec{VQC} \equiv (\vec{PC}_1QC_1, ..., \vec{PC}_{30}QC_{30})'$$

(37)

$$= M'\vec{VQI}^u$$

$$QC_i = \frac{\vec{VQC}_i}{\vec{PC}_i}$$

(38)

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4 Our setup is identical to our model for the U.S. as described in Jorgenson and Wilcoxen (1990).
The input-output USE matrix in share form (from eq. 20-22) is:

\[ A_{1j} = SP_i^M * SP_j^{TOP} \]
\[ A_{2j} = SP_i^E * SP_j^{TOP} \]
\[ \cdots \]
\[ A_{30j} = SP_i^{25} * SP_j^{TOP} \]

\[ A_j \equiv (A_{1j}, A_{2j}, ..., A_{Nj})' \quad j \in IND \]

\[ A = [A_1, A_2, ..., A_N] \]

For the value added rows, the value of the labor input is given by:

\[ \tilde{PL}_j(\tilde{LD}_j + \tilde{D}_j) = SP_i^{TOP} * \tilde{P}O_j * QI_j \]

The cash flow from industry \( j \), which is shared between controlled and market capital, is:

\[ CF(K_j) = (1 - tv_j)\tilde{PK}_jK_D + TR_i^P + TR_i^L - TR_i^Q + GENT_j \]
\[ = \tilde{P}O_jQI_j - PT_jTD_j - PL_jLD_j - \sum_i \tilde{P}S_iQP_i^j \]
\[ + TR_i + TR_i^L - TR_i^Q + GENT_j \]
\[ = \tilde{P}O_jQI_j + \tilde{P}_jQI_j - PT_jTD_j - PL_jLD_j - PL_jLD_j \]
\[ - \sum_i \tilde{P}S_iQP_i^j - \sum_i \tilde{P}_iQP_i^j + GENT_j \]

We have introduced another term \( GENT_j \), to denote direct grants from the government to enterprises. This is merely for accounting consistency. While these grants or subsidies are mostly for loss making enterprises we ignore this aspect and treat them exogenously, keeping them only to match the data on government expenditures and the cash resources of each sector in the sample period.

We add to this cash flow the other property income – rental from non-agriculture land holdings, \( T_j \), to give property income:

\[ Y^{prop} = \sum_j CF(K_j) + \sum_{j \neq 1} PT_jT_j \]

The property income is taxed and the remainder is mostly kept as retained earnings, \( RE \). Some of it is distributed as dividends, \( DIV \), to domestic owners and some as “net factor payments” (\( NFY \))
to the rest of the world. A portion of it is paid to the government as nontax payments, $TAXN_{ent}$, these includes various fees and charges:

$$Y^{prop} = \sum_j tax(K_j) + DIV + RE + NFY(B^*) + TAXN_{ent}$$ (45)

We have used $T_j$ to denote the supply of land by “land owners” to distinguish it from $TD_j$, the demand for land by producers. These are of course equal in equilibrium. As discussed above, rent from the agriculture sector is our own construction and is added directly to total household income. Land rent from the crude petroleum and gas mining sectors is treated as property income and subject to the profits tax, i.e. it is included to make $tax(K_j)$ equal to the total tax actually paid by sector $j$ in the base year.

In other words, part of what has been officially recorded as labor income to farmers we have relabelled as rental income to farmers; and what is recorded as profits and depreciation in the IO table we relabel as capital input and land rental.

The tax payable by the individual sectors $j$ has been changing through the years of economic reform. Until the tax reform that took place at the beginning of 1994, tax rates were highly differentiated across sectors and ownership types. Even today they still are not completely uniformly applied. Enterprise taxation is a mixture of output tax, value added tax and profits tax. We have already described the sales tax and VAT. The profits tax is represented as:

$$tax(K_j) = tk(PKD_jKD_j + PT_jTD_j)$$ (46)

The remaining terms on the RHS of (45) is allocated as follows. $NFY$ is set exogenously and the division of the remaining after tax income into $RE$ and $DIV$ is made in a simple fixed share manner that replicates our SAM for 1995:

$$DIV = div\_share \times Y^{prop}$$ (47)

The value of the “dividend” payout ratio, $div\_share$, is 1995 was 0.46

4 Households

Our model is specified in a way very similar to the Solow growth model. There is an aggregate household and savings is set as an exogenous share of income. This savings then translate to aggregate investment. Utility in each period depends only on consumption in that period, we do not allow for leisure in this model. The effective size of the aggregate household changes over time.
with the size, as well as the composition, of the population. These determine the quantity of labor supplied. (In future versions of the model when further data becomes available, the composition of the population will affect the composition of consumption demand, e.g. more elderly demanding more health services.)

Let \( \text{POP}_t \) denote the total population in period \( t \), and \( \text{POP}^w_t \) denote the working age population (ages 16-60). The exogenous supply of labor is expressed as a measure of effective hours which is given by:

\[
\text{LS}_t = \text{POP}^w_t \cdot h_r_t \cdot q^L_t
\]

where \( h_r_t \) denotes the annual hours of an average worker and is projected exogenously as described in section 11. If one expects a fall in underemployment then one would project a rising \( h_r_t \). \( q^L_t \) is an index of the quality of aggregate labor. This allows for an increase in the average level of educational attainment as schooling expands and a rise in average experience as the workforce ages. (This follows the treatment of labor input in the U.S. discussed in Ho and Jorgenson 1999.)

The labor supply \( \text{LS}_t \) is equal to the total labor demand in equilibrium (eq. 150 below). As described in section 3 above, labor demand is divided into fixed and market components. The after-tax labor income generated is:

\[
Y(\text{LS}) = (1 - t^a)[ \sum_j (1 - t_{v_j})(P_{L_j}L_{D_j} - T R^L_j)]
\]

\[
= (1 - t^a)[ \sum_j (1 - t_{v_j})(P_{L_j}L_{D_j} + P_{L_j}L_{D_j})]
\]

This is the main source of household income, the total private household disposable income in period \( t \) is given by:

\[
Y^p_t = Y(\text{LS}) + PT_1T_1 + DIV + G_I + \text{G-transfer} + \text{R-transfer} - TAXN^{hh}
\]

where \( PT_1T_1 \) is the agriculture land rental, \( DIV \) is the distributed profits and interest (“dividends”), \( G_I \) is government interest payments on its bonds, \( \text{G-transfer} \) is government transfers to individuals, and \( \text{R-transfer} \) is unrequited transfers from the Rest of the world. \( TAXN^{hh} \) is nontax payments to the government (fees and other charges).

Out of this income an exogenous share goes to private household savings:

\[
S^p_t = s_t Y^p_t
\]

This share, while exogenous, may vary with time. The projection of the share is described in section 11. Let the value of total consumption expenditures be \( CEXP \), total private income is thus allocated.
as:

\[ Y_t^p = CEXP_t + S_t^p \]  (53)

The household maximizes a utility function defined over the 30 commodities:

\[ U(C_1, \ldots, C_{30}, t) \]  (54)

subject to the budget constraint:

\[ CEXP = \sum_i P_i^C C_i \]  (55)

where \( P_i^C \) is the market price of commodity \( i \) to the household sector and may include further (explicit) consumption taxes or subsidies:

\[ P_i^C = (1 + t_{ci}) \overline{PS}_i \quad i \in I_{COM} \]  (56)

In the case where \( U \) is of the Cobb-Douglas form, \( U = \sum_i \alpha_i^C \log C_i \), the demand for \( i \) is:

\[ C_{it} = \alpha_{it}^C \frac{CEXP_{it}}{P_i^C} \quad i \in I_{COM} \]  (57)

The analysis in equations (52-56) holds exactly for a completely marketized system. The Chinese plan, however, still contain some rationed elements. We shall represent the plan as the household being entitled to a quantity \( \bar{C}_i \) for which they pay a lower price \( \bar{P}_i \). As in the production sectors, we assume trivially that households wish to consume more than \( \bar{C}_i \) at the prevailing market prices. The implicit transfer to the household sector is therefore:

\[ TR^C = \sum_i (P_i^C - \bar{P}_i) \bar{C}_i \]  (58)

and the expenditure constraint (54) is modified to:

\[ CEXP = \sum_i P_i^C \bar{C}_i + \bar{P}_i \bar{C}_i = \sum_i P_i^C C_i - TR^C \]  (59)

where \( C_i = \bar{C}_i + \bar{C}_i \) is now given by:

\[ C_{it} = \alpha_{it}^C \frac{CEXP_{it} + TR^C_{it}}{P_i^C} \quad i \in I_{COM} \]  (60)

We construct indexes of aggregate consumption and aggregate price:

\[ \log P_{iCC} = \sum_i \alpha_{it}^C \log P_i^C \]  (61)
The consumption-savings relation (52) may now be rewritten as:

\[ Y^p_t + TR^C_t = P^{CC}t CC_t + S^p_t \]  \hspace{1cm} (63)

The Consumption column in the input-output table in quantity terms is thus simply:

\[ C \equiv (C_1, C_2, ... , C_N)' \]  \hspace{1cm} (64)
5 Capital and Investment

Recent reforms in the Chinese economy have only served to further complicate the property rights structure. On the one hand, there are state enterprises where control nominally rests with one or another level of government. On the other hand, there are collectives, private enterprises, and foreign-invested joint ventures which usually have greater control over their assets.

We shall abstract from this complex reality and focus on a few important features. We regard the existing capital in each industry to be fixed, that is, it may not be rented out to other sectors in any period of the simulation. Denoting this by $\bar{K}_{jt}$ we have:

$$\bar{K}_{jt} = (1 - \delta)\bar{K}_{jt-1} + \psi^j_t \Pi_{jt} \quad j \in I_{IND}$$  \hspace{1cm} (65)

Government investment through the state budget and directed bank loans, $\Pi_{jt}$, contributes to these stocks of capital. These are projected to fall over time, and with depreciation at rate $\delta$ the importance of this capital will gradually diminish. $\bar{K}_{j0}$ is the capital in sector $j$ in the latest year of the data sample.

To model the emergence of a market in capital (including the stock exchanges) we include market capital, $\bar{K}_t$, that is mobile and competitive:

$$\bar{K}_t = \sum_j \bar{K}_{jt}$$  \hspace{1cm} (66)

$$\bar{K}_t = (1 - \delta)\bar{K}_{t-1} + \psi^0_t \Pi^0_t$$  \hspace{1cm} (67)

$\bar{K}_{jt}$ is the portion rented to industry $j$, and $\Pi^0_t$ is the aggregate market investment. $\psi^0_t$ is an aggregation coefficient that reconciles the investment units to the stock units.\(^5\) This market investment comes from the unrestricted part of retained earnings, savings of the households, and foreign investment. The savings-investment balance is discussed in Section 7, below. The rate of depreciation $\delta$ is assumed to be the same for both types of capital.

The total capital available for use by industry $j$ in period $t$ is thus:

$$K_{jt-1} = \bar{K}_{jt-1} + \bar{K}_{jt-1}$$  \hspace{1cm} (68)

\(^5\) The composition of investment (say, the ratio of buildings to equipment) is different from the composition of the capital stock. The construction of the price of aggregate investment is thus different from the one for the stock. The $\psi$ coefficients in this model are used to reconcile the model’s aggregate variables to the actual disaggregated data that underlie these variables.

15
The allocation of market capital to the various sectors is based on rates of return. We shall make a simplifying assumption that all sectors rent an identical bundle of capital, i.e. ignoring that they actually use different proportions of buildings, machinery, equipment, etc. With this assumption, the rate of return and the rental rate paid by the industries \((PKD_j)\) differ by a common constant rate of depreciation. We therefore write the allocation of market capital as a function of the rental prices, and choose a simple translog functional form:

\[
\frac{PKD^s_{jt}}{PKD_t \bar{K}_{t-1}} = \alpha + \sum_i B_{ij} \log PKD^s_{it}
\]

where the total rental income is:

\[
PKD^s_t \bar{K}_{t-1} = \sum_j PKD^s_{jt} \bar{K}_{jt-1}
\]

The rate of return to the aggregate market capital, \(r_t\), is given by:

\[
r_t PK_{t-1} \bar{K}_{t-1} = \sum_j PKD^s_{jt} \bar{K}_{jt-1} - tax(\bar{K}_{t-1}) - \delta PK_t \bar{K}_{t-1}
\]

where \(tax\) denotes the total tax payable on capital income. \(PK_t \bar{K}_t\) is the value of the stock and the determination of the price \(PK\) is discussed later in this section.

The rate of return to the plan capital in \(j\) is similarly given by:

\[
\bar{r}_j PK_{t-1} \bar{K}_{t-1} = PKD^s_{jt} \bar{K}_{jt-1} - tax(\bar{K}_j) - \delta PK_t \bar{K}_{jt-1}
\]

(Comment. We have valued the plan capital at the price \(PK\) which is actually the price of the market capital. In a model with portfolio choice eq. (71) would be reversed, the market in financial assets would produce a required rate of return, \(r_j\), and eq. (71) would determine the price of the fixed stock of capital, \(PK_j\). In this model without perfect foresight these prices of capital does not play an important role and we shall take the simplest approach of using a common price \(PK\). This also have the advantage of showing the low rates of return in the sectors with a large plan component and where the plan output price is set very low.)

We now turn to the composition of investment demand. The aggregate market investment, \(\Pi^a\), is made up of the 30 commodities. Following the official data we also divide investment into fixed investment and inventory investment. The value of total market investment is:

\[
PII^a \bar{\Pi}^a = PII^f \bar{\Pi}^f + PII^v \bar{\Pi}^v
\]

where \(PII^a\) is the price of aggregate investment, and \(PII^f\) and \(PII^v\) are the prices of fixed and inventory investment. We use a simple Cobb-Douglas aggregation of these two components:

\[
\bar{\Pi}^a = PII^f \alpha_j PII^v (1 - \alpha_j)
\]
The quantity of total fixed and inventory investment is thus simply:

$$\tilde{I}^v = (1 - \alpha_f^v)\frac{\text{PII}_a^v \tilde{I}^f_a}{\text{PII}_a^v} \quad \tilde{I}^f = \alpha_f^f \frac{\text{PII}_a^f \tilde{I}^f_a}{\text{PII}_a^f}$$  \hspace{1cm} (76)

We also divide the fixed investment into the 30 components using a Cobb-Douglas function:

$$\log \tilde{I}^f_i = \sum_i \alpha_i^f \log \tilde{I}^f_i$$ \hspace{1cm} (77)

$$\tilde{I}^f_i = \alpha_i^f \frac{\text{PII}_a^f \tilde{I}^f_a}{\text{PII}_a^f} \quad i \in I_{COM}$$  \hspace{1cm} (78)

where $\tilde{I}^f_i$ is the quantity of fixed investment in commodity $i$, and $\tilde{P}S_i$ is the market price of $i$. Similarly, for inventory investment we have:

$$\log \tilde{I}^v_i = \sum_i \alpha_i^v \log \tilde{I}^v_i$$ \hspace{1cm} (79)

$$\tilde{I}^v_i = \alpha_i^v \frac{\text{PII}_a^v \tilde{I}^v_a}{\text{PS}_i} \quad i \in I_{COM}$$  \hspace{1cm} (80)

The $\alpha_i^f, \alpha_i^v$ share parameters are the shares based on the latest IO table but may be set exogenously to different values for each period of the projection. The shares of course must sum to one and these value identities hold:

$$\text{PII}^f \tilde{I}^f = \sum_i \text{PS}_i \tilde{I}^f_i \quad \text{PII}^v \tilde{I}^v = \sum_i \text{PS}_i \tilde{I}^v_i$$  \hspace{1cm} (81)

Total market investment purchases of commodity $i$ is the sum of fixed and inventory investment:

$$\tilde{I}_i = \tilde{I}^v_i + \tilde{I}^f_i$$  \hspace{1cm} (82)

Lacking an obvious way to project plan investment by commodities we shall assume that they follow the same pattern as the market investment described above, i.e., using value shares from the latest IO table. Total investment, plan plus market is therefore simply:

$$I_i = \tilde{I}_i \frac{\text{PII}_a^v \tilde{I}^v_a}{\text{PII}_a^v \tilde{I}^v} \quad i \in I_{COM}$$  \hspace{1cm} (83)

We now have the investment column of the input output table:

$$I = (I_1, \ldots I_N)'$$  \hspace{1cm} (84)
The market value of total investment is

$$PII^a III^a = PII^a \Pi + PII^a \Pi^a = \sum_i PS_i I_i \tag{85}$$

A remaining item to consider is the implicit subsidy to the investing enterprises when some of the investment commodities are allocated at fixed plan prices. We shall treat this in a way parallel with the plan elements of household consumption. A quantity $I_i$ of commodity $i$ is sold to the “plan investor” at price $\bar{P}_t$ with a resulting implicit transfer of:

$$TR^I_t = \sum_i (\bar{PS}_i - \bar{P}_t) I_i \tag{86}$$

Recalling plan investment from eq. (64), the total value of plan investment in period $t$ for the whole economy is:

$$\sum_j PII_t \Pi_{jt} = \sum_i \bar{PS}_{it} I_{it} \tag{87}$$

The actual expenditures on total investment after taking into account this transfer is:

$$PII^a III^a - TR^I_t \tag{88}$$

Writing the capital accumulation equations like the way we have in (64) and (67) mean that one unit of aggregate investment translate into $\psi^I$ units of capital stock. That is, installed capital is substitutable for new investment at this rate. This is in contrast to models with adjustment cost that distinguish between installed and new capital, and which therefore have different prices for I and K. Our simplifying assumption thus impose a simple relation between the price of capital stock and the price of investment:

$$PK_t = \psi^I_t PK I_t^a \quad \psi^PK = 1/\psi^I \tag{89}$$
6 Government and Pollution taxes

The role of the government in the Chinese economy is bigger than that of typical market economies as we have emphasized above. Our model reflects this. We have already described how the government plan affects the output and factor markets, we shall now describe the more familiar public role in taxation and expenditure. As can be seen from Figure 1 the government collects taxes from the producers and the foreign sector, and purchases public goods (including labor), transfer money to the household sector, transfer funds for plan investment, pays subsidies for various purchase, and pay interest on the public debt. It also borrows from the household and from the ROW to finance the deficit.

Turning first to taxes, previously most of the Chinese government’s revenue came from state enterprises. Examples include oil exports sold at world prices and paid for at low state-set prices, and sales of high priced manufactured products made from materials obtained at low plan prices. There was no personal income tax and little foreign trade. Now, with the tax reform of 1994, there is a broad-based value added tax covering all the industrial sectors (mining, manufacturing, utilities) and commerce. There is a personal income tax but few individuals have high enough incomes to be affected and it generates little revenue currently. With the heightened interest in the environment, pollution charges and fines have been imposed. Another source of nontax receipts are fees from public services like health care.

The public finance accounts of China includes entities classified as “extra-budget” with their own receipts and expenditures. We consolidate them all into the “government” sector. The public finance data of China is not yet integrated with the national accounts and thus a systematic accounting of private versus public savings is not possible. There is also no official reconciliation of the flow of deficits and the stock of public debt. We make a set of estimates based on Chinese and World Bank data. This is described in the data section below.

We will be interested in simulating the effect of various taxes like sales taxes, labor taxes or carbon taxes. We therefore introduce some tax variables into the model even though they are currently zero. We have introduced the full sales tax per yuan of output in eq. (32) earlier:

\[ tt_j^f = tt_j - ts_j + tx_j^v + \frac{tx_j^n}{PO_j} + \frac{tp_j^P}{PO_j} \] (90)

where \( tt_j \) is the sales tax on the output of \( j \), \( ts_j \) is the subsidy for the output, \( tx_j^v \) is the externality


\[ \text{Information about the VAT is given in Finance Ministry (1998)} \]
tax based on the value of the good \( j \) used, and \( tx^u_j \) is the externality tax based on the quantity of \( j \) consumed. It is easiest to think of the externality tax as, say, a carbon tax on the output of industries 2 and 3 (coal mining and crude petroleum). \( tx^u_2 \) would then be the tax per ton of average coal and \( tx^u_3 \) would be the tax per ton of oil. In the model the \( tx \)'s are actually vectors for various externalities, e.g. a carbon tax, a sulphur dioxide tax, etc. Pollution taxes or fines may also be levied on the level of output, e.g. the fees on waste water discharge. These are represented by \( tp^P_j \). These externality taxes are also placed on imports \( M_i \) (discussed in the next section).

The revenue from the sales and externality taxes on output are:

\[
R_{\text{SALES}} = \sum_j t_j \bar{PO}_j QI_j
\]

(91)

\[
R_{\text{EXT}} = \sum_i tx^i_j (PO_i QI_i + PM_i M_i) + \sum_i tx^i_j (QI_i + M_i) + \sum_j tp^P_j QI_j
\]

(92)

The second item on the RHS of (32) is the rate of subsidy. The total government expenditures on output subsidies amount to:

\[
G_{\text{SUBSID}} = \sum_j ts_j \bar{PO}_j QI_j
\]

(93)

The next important source of revenue is the tax on value added. For the sectors that are not subject to the VAT we simply set \( tv_j = 0 \). The revenue is given by:

\[
R_{\text{VAT}} = \sum_j tv_j (PKD_j KD_j + PLD_j LD_j + PT_j TD_j)
\]

(94)

Finally, there is an enterprise profits tax which we regard as a tax on property income. The actual tax code is of course quite complicated with different rules for foreign and domestic corporations, different tax rates for different industries, etc. We shall simplify this and express the taxes on enterprises as a common tax rate, \( tk \), applied to total capital income. The revenue from these taxes are:

\[
R_{\text{K}} = \sum_j tk_j (1 - tv_j) PKD_j KD_j + \sum_{j=3,4} tk_j (1 - tv_j) PT_j TD_j
\]

(95)

Most developing countries obtain a substantial fraction of revenue from taxes on international trade. In the case of China this is done for many years through the government’s monopoly on trade exercised by the Foreign Trade Corporations (FTC). For example, oil is exported at world
prices but the mining companies are paid only a fraction of this world price. Imports of cars are sold to domestic buyers at prices much higher than world prices. This is no longer very important. There are also non-tariff barriers like quotas. We shall ignore much of these and represent only the tariffs on imports, and VAT rebates on exports. These taxes are described in greater detail below in Section 7 (Rest of the World). For now, let us just express the total tariff revenue as:

\[ R_{\text{TARIFF}} = \sum_i t_{ri} eP M^*_i M_i \]  

(96)

where \( t_{ri} \) is the tariff rate on the import of commodity \( i \).

The rebate on VAT for exports is given by:

\[ R_{\text{REBATE}} = \sum_i \frac{se_i}{1 + se_i} \widehat{PC}_i X_i \]  

(97)

and \( se_i \) is the rebate rate on the export of \( i \).

For modeling purposes we introduce 2 taxes that are not currently used, a tax on consumption commodities, \( C_i \), purchased by households, and a tax on labor income:

\[ R_{\text{CON}} = \sum_i t_{ci} SP_i C_i \]  

(98)

\[ R_{\text{L}} = tl^w [\sum_j (1 - t_{vj})(\widehat{PL}_j \widehat{LD}_j + PL_j LD_j)] \]  

(99)

\( tc_i \) is not a typical tax (or subsidy if it is negative), it is a tax imposed only on households but not on any other buyers of commodity \( i \). An example might be a tax on private cars but not on company ones.

Finally, the nontax receipts of the government from households and enterprises are modeled in as simple a manner as possible by setting them as fixed shares of GDP for the projections:

\[ TAXN^{hh} = \gamma_i N^{hh} GDP_t \]  

(100)

\[ TAXN^{ent} = \gamma_i N^{ent} GDP_t \]  

(101)

These are essentially direct government decisions on the fees and charges like health care fees, university fees, etc.

The total revenue of the government is thus:

\[ REVENUE = R_{\text{SALES}} + R_{\text{TARIFF}} - R_{\text{REBATE}} + R_{\text{CON}} + R_{\text{VAT}} + R_{\text{K}} + R_{\text{L}} + R_{\text{EXT}} + TAXN^{hh} + TAXN^{ent} \]  

(102)
Turning now to public expenditures, these may be divided into the broad items of government purchases of commodities, transfers to households, grants and subsidies to enterprises, and interest payments. Let $G_I$ denote the interest paid to domestic holders of government debt and $G_{IR}$ be the interest paid to the ROW. We write these as an exogenous interest rate multiplied by the stocks of domestic and foreign debt ($B_t$ and $B_t^{G*}$):

$$G_I = i_t B_{t-1}$$  \hspace{1cm} (103)  

$$G_{IR} = i_t^a B_t^{G*}$$  \hspace{1cm} (104)  

Government transfers to the household sector is another sizable expenditure and includes items like retirement payments and welfare payments. These are set directly by policy and for simplicity we shall project them as the population multiplied by the wage rate to let it rise with the general increase in real wages:

$$G_{\text{transfer}} = \gamma_t PLD_t POP_t$$  \hspace{1cm} (105)  

For the first year of the simulations these interest and transfers are set to the actual flows given in the SAM in Figure 2.

As previously discussed in the Capital and Investment section the government allocates investment funds directly to some enterprises in what it regards as key sectors. We shall represent this government direct investment, $G_{\text{INV}}$, as a share of total economy investment:

$$G_{\text{INV}} = \gamma^I_t PI^I_t II^I_t$$  \hspace{1cm} (106)  

where the share, $\gamma^I_t$, is set exogenously and may decline over time as a matter of public policy. How this fund joins total national savings is discussed in Section 8 (Markets) below. The government also gives direct subsidies to some loss making enterprises. This has declined in importance but is still there and for accounting completeness we shall include the expenditure item $G_{\text{ENT}}$ to represent these direct grants to enterprises.

$$G_{\text{ENT}} = \sum_j GENT_j$$  \hspace{1cm} (107)  

Total expenditures may now be written as:

$$EXPEND = VGG + G_{\text{SUBSID}} + G_I + G_{IR} + G_{\text{transfer}} + G_{\text{INV}} + G_{\text{ENT}}$$  \hspace{1cm} (108)
where $VGG$ is the value of total government purchases of commodities (which includes the public sector workers of industry 30, “Public Administration”) and $G_{SUBSID}$ is the subsidies on output given above in eq. (92). We shall represent government demand for goods in a simple manner as a fixed share of the total $VGG$:

$$\tilde{PS}_i G_i = a_i^G VGG \quad i \in I_{COM}$$  \hspace{1cm} (109)

These $a_i^G$ coefficients are set to the latest available input output table. This then gives us the IO table’s final demand column for government demand:

$$G \equiv (G_1, G_2, ..., G_N)'$$  \hspace{1cm} (110)

The difference between the expenditures and revenue gives us the public deficit:

$$\Delta G_t = EXPEND_t - REVENUE_t$$  \hspace{1cm} (111)

This deficit is set exogenously. It matches the sample period’s deficits in the near term and declines to zero over time. Substituting in the details of EXPEND and REVENUE from (108) and (102) we can see how this equation determines the level of expenditures on commodities, $VGG$. Tax rates are fixed, the revenue depends endogenously on the level of economic activity, the deficit is exogenous, and the expenditure items other than $VGG$ is determined by eq. (102-106) above.

The deficit cumulates into the stock of debt, which consists of domestic debt and foreign government debt:

$$B_t + B_t^{G*} = \Delta G_t + B_{t-1} + B_{t-1}^{G*}$$  \hspace{1cm} (112)

$B_t$ includes both government bonds and money which has been growing rapidly in a few particular years in the 1990s. The allocation of the deficit finance between domestic and foreign borrowing is done by exogenously, i.e., $\Delta G$, $B$ and $B^{G*}$ are all exogenous.

### 6.1 Externalities and pollution taxes

We shall divide pollution into two types, production externalities and consumption externalities. The first is due to the production of goods and includes the official categories of waste water, waste gas and waste solids (these are sometimes called process emissions). This pollution may change with different production technologies and different material inputs, and may be abated at some cost. The second type may be thought of as greenhouse gases, e.g. carbon dioxide from the burning of
fossil fuels. The link between the consumption of fuels and the emission of CO\textsubscript{2} may not be changed easily, if at all, and abatement is extremely costly (e.g. carbon sequestration).

Let \( p \) and \( x \) be the index of these two sets of externalities:

\[
p \in \{ \text{TSP, waste water, smog, waste solids} \}
\]

\[
x \in \{ CO_2, TSP, SO_2, ... \}
\]

The quantity of production externality of type \( p \) from sector \( j \) is calculated as a fixed coefficient of output, \( XP_{jp} \), a coefficient that may change over time, or be reduced by abatement expenditures. The total national output of pollution \( p \) is given by:

\[
EXT_P = \sum_j XP_{jp} QI_{jt}
\]

(113)

Similarly, the emission of \( x \) from the use of domestic commodity \( i \) is given by the coefficient \( XU_{ix} \) and the emission from one unit of import \( i \) is \( XM_{ix} \). (Given our level of aggregation the “average” ton of oil that is imported may be different from the domestic unit and we therefore allow the coefficients to be different. There is, however, as yet no data to separate out the coefficients.) The total emission of \( x \) is then:

\[
EXT_x = \sum_i XU_{ix}(QI_i - X_i) + \sum_i XM_{ix} M_i
\]

(114)

We now turn to the calculation of the pollution taxes introduced in eq. (32). Let us think of a carbon tax as a concrete example, i.e. \( x = CO_2 \). Let the tax based on the carbon content of fuels be \( tx^x XU_{ix} \) per ton of carbon emitted. The carbon tax on one unit of oil (commodity 3) would then be \( tx^x XU_{3,ix} \). The revenue from the carbon tax will be \( \sum_i tx^x XU_{i,CO2} QI_i \).

If there are taxes on other types of pollution (e.g. \( x = TSP, SO_2 \)) then the total externality tax on domestic commodity \( i \) would be:

\[
tx^a_i = \sum_x tx^x U_{ix}
\]

(115)

This is the tax rate that appears in eq. (32). For imports, the total externality tax on \( i \) is:

\[
tx^r_i = \sum_x tx^x XM_{ix}
\]

(116)

If the pollution tax is based on values rather than unit output then we have:

\[
tx^v_i = \sum_x tx^x U_{ix}
\]

(117)

\(^8\)The first group of pollution is analysed in Xie (1995) while the second group is the focus of more attention, Garbaccio, Ho, Jorgenson (1999b) and Rose et. al. (1995) among others.
\[ tx_i^{rv} = \sum_x tx_x^v XM_x \]  

(118)

For the first type of externalities, the production pollution, we impose a tax of \( tp_p^p \) per unit of pollution of type \( p \). The total tax on a unit of output from industry \( j \) is then:

\[ tp_j^p = \sum_p tp_p^p XP_{jp} \]  

(119)

Specific case of the carbon tax.

Carbon is measured in tons, and in the Chinese accounts for the fuels, coal and oil are in tons while natural gas is in \( m^3 \). The quantities in the model, \( QI_j \) are, however, in constant Yuan units, and we need to convert the units carefully. We use the following scheme:

\( QI_2 = \) output of “Coal Mining”
\( QI_3 = \) output of “Crude Oil”
\( QI_4 = \) output of “Natural Gas”
\( QI_{13} = \) output of “Petroleum Refining”

\[ coal_t = q_{coal}QI_{2t} \quad \text{(bil.tons)} \]  

(120)

\[ oil_t = q_{oil}QI_{3t} \quad \text{(bil.tons)} \]  

(121)

\[ gas_t = q_{gas}QI_{4t} \quad \text{(bil.m}^3\text{)} \]  

(122)

\[ energy_t = e_{coal}coal_t + e_{gas}gas_t + e_{oil}oil_t - en\_exports \]  

(123)

\[ en\_exports = e_{coal}q_{coal}(X_2 - M_2) + e_{oil}q_{oil}(X_3 - M_3) + e_{gas}q_{gas}(X_4 - M_4) + e_{oil}q_{oil}(X_{13} - M_{13}) \]  

(124)

\[ EXT_{CO2} = \sum_{j=2,3,4} c_j e_j q_j (QI_j - X_j + M_j) - c_{oil} e_{oil} q_{oil} (X_{13} - M_{13}) \]  

(125)

where \( q_{coal} \) is the number of tons of coal per unit of \( QI_2 \), \( q_{oil} \) is the number of tons of oil per unit of \( QI_3 \), and \( q_{gas} \) is the number of \( m^3 \) of natural gas per unit of \( QI_4 \).

The quantity of energy used (in SCE’s), \( energy_t \), is then calculated with the energy coefficients \( e_{coal}, e_{oil}, \) and \( e_{gas} \) (\( e_{oil} \) translate tons of oil into tons of SCE, for example). Finally, the emissions of carbon as \( CO_2 \) is calculated using the \( c \) coefficients which translate SCE’s into tons of carbon.
7 Rest of the World

This is a one-country model and the rest of the world sector (ROW) is modeled quite simply. The goods produced in the ROW are considered to be imperfect substitutes with those produced in China, the usual Armington assumption in models of this kind. Relative prices of foreign goods are fixed exogenously. Exports face a downward sloping demand and the current account balance is set exogenously. A world relative price is the endogenous variable used to meet the exogenous current account.

Imports.

Let $PM^*_i$ be the world price of importable good $i$. The price to domestic buyers is this world price plus tariffs, the tax by the Foreign Trade Corporation, and pollution taxes:

$$PM_i = e(t + tr + tx^r)PM^*_i + tx^ru, \quad i \in I_{COM} \quad (126)$$

$e_t$ is the world relative price variable which converts the foreign currency price (so to speak) $PM^*_i$ to domestic price units. With this specification, $\frac{PM^*_i}{PM^*_j}$ is fixed for any two commodities $i$ and $j$, and the ratio that is endogenous is $\frac{PM_i}{PM_j}$.

The total supply of commodities is the sum of domestic and imported varieties, the value of the supply of $i$ at market prices is:

$$PS_iQS_i = PC_iQC_i + PM_iM_i \quad (127)$$

We shall write the total quantity supplied, $QS$, as a CES function of the two varieties:

$$QS_i = \left[ \frac{QC^p_i}{d_{it}} + \frac{M_{it}^{\rho_i}}{m_{it}} \right]^{1/\rho_i}, \quad i \in I_{COM} \quad (128)$$

The price dual of this aggregation function is:

$$PS_i = \left[ \overline{PC_i}^{\rho_i} d_{it}^{\sigma_i} + PM_i^{\rho_i} m_{it}^{\sigma_i} \right]^{1/\rho} \quad r = \rho/(\rho - 1) \quad (129)$$

$\rho_i \in (1, -\infty)$ \quad $\sigma_i = 1/(1 - \rho_i) \in (\infty, 0) \quad (130)$

$d_{it}$ and $m_{it}$ are the domestic and imported share coefficients and is indexed by time. These are allowed to change over time because of the rise in imports unexplained by price changes. This problem is discussed at greater length in Ho and Jorgenson (1994) which has a similar treatment of imports.

The value share of imports derived from this CES function is:

$$SM_i = \frac{PM_iM_i}{PS_iQS_i} = \frac{m_iPM_i}{d_iPC_i + m_iPM_i} \quad (131)$$
We shall make use of the following notation for the import share and domestic share vectors:

\[ SM = (SM_1, \ldots, SM_N)' \]  

(132)

\[ SD = 1 - SM \]  

(133)

\[ VQC = \text{Diag}(SD)VQS \]  

(134)

The following is derived from (120) and is a useful equation for the solution algorithm:

\[ M_i = \frac{SM_i}{1 - SM_i} \frac{PC_i QC_i}{PM_i} \]  

(135)

Exports.

Turning to exports, we write these as functions of some base export and a term that depends on the price of domestic goods relative to the world price. Let \( EX_{it} \) denote the base exports, i.e. exports that would be made at base year’s relative prices. The exports of commodity \( i \) in period \( t \) is:

\[ X_{it} = EX_{it} \left( \frac{(1 + tr^* i) PC_{it}}{e_i(1 + se_i) PE_{it}} \right)^{\eta_i} \]  

(136)

where \( PE^*_i \) is the world price of the ROW variety and \( tr^* \) is the world tariff. \( e_t \) is the same world relative price variable that appears in the import price equation above. Base exports \( EX_{it} \) are set exogenously.

From (135) and (136) we now have the last two Final demand columns, exports and imports:

\[ M \equiv (M_1, \ldots, M_N)' \quad X \equiv (X_1, \ldots, X_N)' \]  

(137)

Current Account and Foreign Debt.

The current account balance is the trade balance plus factor payments and transfers. The current account evaluated in domestic prices is:

\[ CA_t = \sum_i \frac{PC_{it} X_{it}}{1 + se_i} - \sum_i PM_i M_i - NFY(B^*) - G_{IR} + R_{\text{transfer}} \]  

(138)

where \( G_{IR} \) is the government interest payments on its foreign debt as described in (104), and \( R_{\text{transfer}} \) is the net unrequited transfers from ROW to China (this appeared in the expression for private income, \( Y^p_t \), in the Households section earlier). These transfers are set exogenously and are
kept merely to maintain accounting consistency, they play no endogenous role in the simulations. 

\( NFY \) is the net private factor payments abroad, we write this as the net private foreign debt multiplied by the interest rate:

\[
NFY_t = r_t^* B_{t-1}^*
\]  

(139)

This variable appeared earlier as one of the components of property income, \( Y_t^{prop} \). While it may be potentially important, it plays no endogenous role in this model since we do not model the ROW sector explicitly in a way complete global models would. That is, we do not describe the world interest rate, \( r_t^* \), endogenously, which means that China is assumed to be able to borrow unlimited amounts at this rate.

The current account deficits cumulate into the stock of foreign debt, private and government:

\[
B_t^* + B_t^{G*} = B_{t-1}^* + B_{t-1}^{G*} - CA_t
\]  

(140)

We do not explain the division of foreign debt into private and public within the model and set all three elements, \( CA_t, B_t^* \) and \( B_t^{G*} \), exogenously.
8 Markets

We have described all the agents in the model in the previous Sections. All the supply and demand functions are specified and we shall now discuss the markets to complete the description of the economy in any period given the inherited stocks of capital, debt and population. The market prices in the model are endogenous, in contrast to the fixed plan prices, and adjust to clear the markets for goods and factors.

Turning first to the market for commodities, the value of final demand for good $i$, evaluated at market prices, is:

$$ VFD_i = \bar{PS}_i(C_i + I_i + G_i) + \bar{PC}_i X_i \quad i \in I_{COM} \quad (141) $$

Define the final demand vector as $VFD = (VFD_1, \ldots, VFD_N)'$.

The total demand for goods is the sum of final and intermediate demands, equating supply and demand for $i$ we have:

$$ \bar{PS}_i QS_i = \sum_j \bar{PS}_j QP^j_i + VFD_i \quad (142) $$

$$ = \sum_j A_{ij} \bar{PO}_i QP^j_i + VFD_i $$

where $A_{ij}$ are the IO coefficients given by eq. (39). In vector notation this is:

$$ VQS = A \bar{VQI} + VFD \quad (143) $$

These markets are cleared by the domestic goods prices $PO$ which in turn determines the buyers price $PI$ through the tax wedge. The make matrix then determines the commodity prices $PC$, and the import equations determine the total supply price $PS$.

Comment. The difference between the market price and the average price is the plan transactions and the following quantity and implicit transfer balances must be observed when projecting the plan elements to preserve the overall supply and demand balance:

$$ C_i + I_i + \sum_j QP_{ij} = QI_i \quad (144) $$

$$ \sum_j TR^Q_j = TR_j + TR^C + TR^I \quad (145) $$

Turning now to the factor markets, for land we have demand equal to supply for the three types of land (agriculture, crude oil, gas):

$$ TD_j = T_j \quad j = 1, 3, 4 \quad (146) $$
These markets are cleared by the rental prices $PT_j$.

For the capital market, the supply of capital ($K_{t-1}$) is given by eq. (67) and the demand ($KD_t$) comes from the producer problem eq. (11). In a one-good world the supply and demand of capital services would be measured in the same units. In our approach we wish to keep the features of the real world data (that capital is made up of many commodities) but also to maintain tractability in the model without having a capital stock variable for each type of asset. So, $K_t$ is the total stock and it is an aggregate of items like buildings, railways and machinery, all of which have very different depreciation rates. The composition of the various components change over time. The flow of aggregate services thus cannot simply be the aggregate stock, and we use an *aggregation coefficient* $\psi^K$ to reconcile the different units. The demand and supply condition is then written as:

$$KD_{jt} = \psi^K_{jt} K_{jt-1}$$  \hspace{1cm} (147)

A fuller discussion of the issues of measuring capital and production functions is given in Ho, Jorgenson and Stiroh (1999). In that paper this aggregation coefficient is called the quality index of aggregate capital. A rise in the quality index reflects a shift in the composition of the aggregate capital stock from long lived assets to short lived ones.

For the labor market, the demand-supply balance in value terms is given by:

$$\sum_j \overline{PL}_{jt} LD_{jt} = \overline{PL}_t LS_t$$  \hspace{1cm} (148)

where $LD_j$ are measured in the units of the production functions in eq. (1). We have chosen to normalize units such that prices are unity in the base year, $PL_{j0} = 1$. In the data we observe that the wage rate per worker varied substantially across the 30 sectors. That is, we must regard one unit of labor supply as being different when used in different industries. Letting $\overline{PL}_t$ be the average market wage in period $t$, we write the industry price of labor as:

$$\overline{PL}_{jt} = \psi^L_{jt} \overline{PL}_t$$  \hspace{1cm} (149)

The labor market balance may be rewritten as:

$$\sum_j \psi^L_{jt} LD_{jt} = LS_t = POP^w \cdot hr_t \cdot q^L_t$$  \hspace{1cm} (150)

It should be recalled (eq. 48) that labor supply is the hours supplied multiplied by an index of quality. The coefficients $\psi^L_{jt}$ may be thought of as indices of labor quality in each industry relative to the national average. (Indices which are normalized to 1 in the base year.)
Finally, we have two identities that are not markets in this model although they could be in other contexts—savings-investment and the current account. In this model without adjustment costs and foresight, savings is investment:

$$S_t^p + RE_t + G\_INV = PII_t^a I_t^a - TR_t + CA_t + \Delta G_t$$

(151)

On the left hand side, total national savings is the sum of private household savings, the retained earnings of the enterprises and government direct allocations for investment. This national savings is used to finance the public deficit, the current account surplus (net foreign investment) and domestic investment (eq. 87). This is not a market equation in the sense that there is a price of savings that equates supply and demand for savings. Eq. (151) is used to calculate investment from national savings. The allocation of a part of these savings to the government debt and foreign debt is done exogenously to maintain accounting consistency and plays no important role here. That is, there are no portfolio choice equations determining the rate of return of debt versus the return from private capital. Of course an exogenous change in the deficit will have implications in that tax rates may be changed and the volume of investment will change but only through eq. (151).

Similarly, the net foreign investment (i.e., the current account surplus) is not modeled endogenously. The supply of $CA_t$ in eq. (138) is not written as a function of a foreign rate of return as in some global models but has an exogenous $CA_t$ target met by the relative price, $e$.

$$CA_t = \sum_i \frac{PC_{it} X_{it}}{1 + se_i} - \sum_i PM_i M_i - NFY(B^*) - G\_IR + R\_transfer$$

9 Local Pollution and Health Effects

In this version 2 of the model the only local pollutants that we shall examine are total suspended particulates (TSP) and sulphur dioxide (SO2). Emissions of these pollutants come from two distinct sources, the first is due to the burning of fossil fuels (combustion emissions), the other from non-combustion processes (process emissions). A great deal of dust is produced in industries like cement production and building construction that is not related to the amount of fuel used. Our current specification of emissions, concentrations, and dose-response follows Lvovsky and Hughes (1997). \(^9\)

\(^9\)We are very grateful to Gordon Hughes who shared the data and explained his methodology for Chapter 3 of World Bank (1997).
Total emissions from industry $j$ is the sum of process emissions and combustion emissions from burning coal, oil, and gas. Let $EM_{jxt}$ denote the emissions of pollutant $x$ from industry $j$ in period and $AF_{jft}$ be the amount of fuel $f$ used (in tons of oil equivalent, toe). Then we have:

$$EM_{jxt} = \sigma_{jx} QI_{jt} + \sum_f \psi_{jxf} AF_{jft}$$

where $x=$\{TSP,SO2\} and $f=$\{coal, oil, gas\}. $\sigma_{jx}$ is the process emission factor while $\psi_{jxf}$ is the combustion emission factor. In addition to the 30 production sectors, the final demand sectors also generates pollution during home heating, cooking and driving. The $j$ index above therefore also includes the household and government sectors.

Estimates of these $\sigma$ and $\psi$ factors have not yet been assembled for many industries in China and will change as new investments are made. A proper study should take into account the costs of these new technologies and how much they reduce emissions and energy use. We use a simple method for determining them following Lvovsky and Hughes (1997). They make an estimate of the emission levels of “new” technology and write the actual emission coefficients as a weighted sum of the coefficients from the existing and new technologies. Using superscripts “O” and “N” to denote the old and new coefficients we have:

$$\psi_{jxf} = k_t \psi_{jxf}^O + (1 - k_t) \psi_{jxf}^N$$

where the weight, $k_t$, is the share of old capital in the total stock of capital. This is an extremely simple approach and ignores the fact that cleaner equipment will likely cost more than dirty equipment. Furthermore, the exogenous energy efficiency improvements described in eq. (17) above are set independently of these emission factors. An integrated approach would of course be preferred when such data becomes available.

Within each of the sectors there is considerable heterogeneity in plant size, vintage, stack heights etc. Unfortunately, we are unable to incorporate such a high level of detail into this work. However, we do note that, on average, different industries emissions enter the atmosphere at different levels. Following Lvovsky and Hughes we classify emission sources as low, medium, and high height. As a first approximation, emissions from the electric power sector are classified as high height, most of the manufacturing industries are classified as medium, and the nonmanufacturing and household sectors as low. The exact designations by sector are given in Table 2. Denoting the emissions of pollutant $x$ at height $c$ by $E_{cxt}$ we have:
\[ E_{\text{ext}} = \sum_{j \in c} EM_{jxt} \quad c = \text{low, med, high} \tag{154} \]

The next step is to estimate concentrations of pollutants in population centers due to these emissions. A good approach would be to disaggregate the emissions by geographic location and feed the data into an air dispersion model which would generate the concentrations at each population center from all sources of emissions. Such an elaborate exercise will have to be deferred to future work. Again we follow Lvovsky and Hughes and use reduced form coefficients to estimate the concentrations. Unlike them, who distinguish between large and other cities, we make a further simplification here and express the national average urban ambient concentration as:

\[ C_{Nxt} = \gamma_{\text{low},x} E_{\text{low},xt} + \gamma_{\text{med},x} E_{\text{med},xt} + \gamma_{\text{high},x} E_{\text{high},xt} \tag{155} \]

where the \( \gamma_{cx} \) coefficients translate emissions at height \( c \) to concentration of \( x \). (If one wishes to index this equation by cities as in Lvovsky and Hughes, one should use a model that calculated economic activity regionally. At a minimum one would need to have projections of population by city to make use of such a disaggregation.)

The next step is to estimate the damage to human health due to exposure to such levels of pollutant concentration. Much debate and research is ongoing about the magnitude of these effects and on how the various pollutants interact. Since much of the existing research has been done in developed countries, questions have been raised as to how these dose-response relationships should be translated to countries like China with very different pollution distributions and populations with different demographic and health characteristics. This is discussed in Wang and Smith (1999, Appendix E) who also cite a range of estimates for mortality effects ranging from 0.04% to 0.30% for a one \( \mu g/m^3 \) increase in PM-10 (see their Table 5). In addition, there is the issue of differential age impacts of these pollutants and the associated difficulty of measuring the “quality of life-years.”

We will not address these important issues here and choose only a simple formulation following Lvovsky and Hughes (1997) which identify eight separate health effects for PM-10 and two for SO2. The most important of these effects are mortality and chronic bronchitis. These effects, indexed by \( h \), are given in Table 3 together with the dose-response relationship, \( DR_{hx} \). The 7.14 number for mortality is interpreted as the number of excess deaths per million people due to an increase in the concentration of PM-10 of one \( \mu g/m^3 \). This is equivalent to a 0.1% mortality effect, which is also the central estimate in Wang and Smith (1999, Table 5).
With these dose-response relationships, the number of cases of health effect $h$ in period $t$ is then given by:

$$HE_{ht} = \sum_x DR_{hx}(C^N_{xt} - \alpha)POP^u_ter h = \text{mortality, RHA, ...}$$

(156)

where $\alpha$ is the WHO reference concentration, $POP^u_t$ is the urban population (in millions), and $er$ is the exposure rate (the share of the urban population exposed to pollution of concentration $C^N_{xt}$).

Various approaches have been used to value these damages in the literature. We use the “willingness to pay” method and follow Lvovsky and Hughes (1997) in using willingness to pay in the U.S. and scaling these by the ratio of per capita incomes in China and the U.S. Using this simple scaling means that we are assuming a linear income effect. The U.S. values associated with each health effect are given in the third column of numbers in Table 3. The next column gives the values scaled using per capita incomes in 1995.

Most studies of health damage valuation would use these estimates for all years of their analysis. However, China is experiencing rapid increases in real incomes. For example, if income rises at an annual rate of 5%, it would have risen 3.4 times in 25 years. A constant health damage valuation would not be appropriate with these large changes in incomes. This issues is complicated if we wish to implement this correctly in an intertemporal optimizing model. However, our model here is myopic, and we choose a simple adjustment by changing the valuation every period in line with income growth, again assuming a linear income effect. The values for 2020 are given in the last column of Table 3. The national value of damage due to effect $h$ is given by:

$$Damage_{ht} = V_{ht}HE_{ht}$$

(157)

where the valuations for 1995, $V_{h,1995}$, are in the third column of Table 3. The value of total damages is simply the sum over all effects:

$$TD_t = \sum_h Damage_{ht}$$

(158)

We should point out that these are the valuations of people who suffer the health effect. This is not the same as calculating the medical costs, the cost of lost output of sick workers, the cost of parents time to take care of sick babies, etc. The personal willingness-to-pay may, or may not, include these costs, especially in a system of publicly provided medical care.
10 Model Notes.

10.1 Number of equations and unknowns.

The above model as written is not homogenous in prices like typical market models since we have the plan elements. To make it homogenous we scale the plan prices relative to a numeraire. The number of equations above is equal to the number of endogenous variables but by Walras Law one of the equations is redundant and one price must be set as numeraire. We choose to set the labor price:

$$\widetilde{PL} = 1.0$$ (159)

For convenient reference, the exogenous variables in this model are:

$T_j, POP_{it}, POP_{it}^w, q^L_i, hr_i, \psi^L_i, \psi^K_i, \psi^N_i, \psi^{PK}_i, \psi^I_i, M_i,$

$B_t, B_t^{Ga}, \Delta G, \gamma^N, \gamma^I, \gamma_t, GENT,$

$B^*, CA_t, R_{transfer}, i^*_t, PM^*_t, d_{it}, m_{it}, EX_{it},$

$\overline{P}_i, \overline{PL}, \overline{C}_i, \overline{QP}_{ij}, \overline{TT}_j, K_j, \overline{LD}_j$

10.2 Numerical note.

In our Fortran implementation of this model our approach to solving it is not to solve all the equations simultaneously but to first triangularize the system. That is, express most of the variables of the model as a function of a small set of basis variables using one equation for each variable, and solve the remaining equations numerically by iterating on the basis variables. We find that we can do this by using the following as basis variables: $PO_{ij}, PKD_j, PT_j, \epsilon, CEXP, V GG, PIIt^{\alpha}, PIIt^{\alpha}.$ This is a small set of 67 unknowns compared to the thousands of endogenous variables in the model (for each period).

This triangulation procedure requires a few more manipulations. Recall from (34) that $VQI^t = \text{Diag}(\epsilon + tt^f)VQI$ and $M = \text{make matrix}$. The commodity market balance equation (143) may be rewritten as:

$$\text{Diag}(1/SD)M\text{Diag}(\epsilon + tt^f)VQI = A \overline{VQI} + VFD$$

$$=> \overline{VQI} = [\text{Diag}(1/SD)M\text{Diag}(\epsilon + tt^f) - A]^{-1}VFD$$ (161)
Our basis variables allow us to calculate final demand \((VFD)\) and the input output matrix \((A)\), and equation (161) gives us the value of industry output. With this output one can calculated the level of input demands and hence tax revenues and incomes.

In the GAMS version of the model we simply solve the whole system of equations defining the equilibrium for period \(t\).

10.3 The Steady State

The Solow growth model above will be characterized by a well defined steady state with a few additional constraints. One, that the income elasticity of demand goes eventually to unity for all commodities (or else, incomes stop rising); two, the rate of technical progress across all sectors is eventually equalized. (These issues are discussed more fully in Jorgenson and Wilcoxen (1990).) With these conditions imposed, then in the long run all relative prices are constant and all quantities in efficiency units are constant. That is, output, consumption and capital per person rises at the common rate of technical progress. The steady state is defined by all the above equations and the following derived from (67):

\[
\psi^I P_{ss} = \delta K_{ss}
\]

Since the plan falls gradually to zero, all capital is eventually market capital, i.e. \(\mathbf{T}_{j,ss} = 0\).
Parameters, Projections of Exogenous Variables and Data sources.

In this section we describe how we projected the various exogenous variables and the sources of our data. The key input is the Social Accounting Matrix (SAM) for 1995. This is assembled from the official 1995 input output table (SSB 1999) by the authors jointly with the Development Research Centre in Beijing. The summary of this SAM is given in Figure 2, the actual matrix used is disaggregated to the 30 sectors and commodities.

The projection process necessarily involve a large element of “guesstimating” and affects the base case fundamentally and we shall show how different projections affect the base simulation. However, this affects the counterfactual comparisons only marginally, i.e. the difference between policy simulations and the base case is not affected very much by different projections of the exogenous variables.

The exogenous variables in the model include total population, working age population, saving rates, dividend payout rates, government taxes and deficits, world prices for traded goods, current account deficits, rate of productivity growth, rate of improvement in capital and labor quality, and work force participation. These variables of course interact among each other and the economy in the real world, but we shall abstract from this complication for now. Some of this is discussed in our previous paper Ho, Jorgenson and Perkins (1995), hereafter referred to as HJP, which uses a more aggregated model of China.

The assumption that matters most is the household savings rate, $s_t$. Our base case assumption is to have $s$ beginning at the observed 29% for 1995 and gradually falling to 20%. National private savings is household savings plus the retained earnings of enterprises. In the recent decade national savings was more than 30% of GDP (Fig. 4 in HJP). The share of retained earnings is assumed to fall, we set $\text{div\_share}$ to rise from 46% to 70%. These two assumptions produce a national savings rate close to 37% as in recent data. (As a comparison, at its peak the Japanese savings rate in the 1960s was 50%, while South Korea’s rate was also above 40% in its period of rapid growth.) It should be pointed out that Savings/Investment in the Chinese data includes public capital such as roads and other public infrastructure, items that are usually excluded in other countries accounts.

In the labor supply expression eq. (48) we have the product of population, annual average hours

\footnote{Development Research Centre, The State Council of PRC. We are very grateful to Li Shantong and Zhai Fan of the Department of Development Strategy and Regional Economy for sharing their data and ideas with us. This Social Accounting Matrix is described in Zhai and Li (2000).}
and quality. Population projections by age groups are taken from World Bank (1995). This is plotted in Fig. 3 together with the working age population. The composition of the work force changes over time with a bigger portion of educated workers, bigger or smaller portion of more experienced workers, and an older average. We track such changes with the \( q^L_t \) index (this is called the quality of labor input in Jorgenson, Gollop and Fraumeni). In the 1950s in the U.S. such a composition index was rising at about 0.5% per annum (Ho and Jorgenson 1999.) Given the small fraction of workers with university education today and the expectation of higher educational attainment in the future we assume that China’s labor quality rises at 0.8% per year initially, falling gradually to a zero growth rate after 60 years.

Total labor hours depends not just on population size but also on the participation rate and annual working hours. While there is virtually no data on the number of hours actually worked per capita, it would seem reasonable to assume that this will rise with a reduction in underemployment, seasonal unemployment and other labor market frictions. We assume that this hours per capita figure rises at 0.5% per year initially, falling to zero growth over thirty years. The combined effect of quality change and hours change is also plotted in Figure 3 where the effective labor supply is set equal to the working population in the initial year.

Similarly capital input \( K_{jt} \) is affected by the composition as noted in footnote 3 and eq. (147). The “quality,” or composition, of aggregate capital has been identified as the major contributor to growth at various periods in post-War East Asia.\(^{11}\) We therefore project conservatively that \( \psi^I_t \) will rise at 2% per year initially, then falling to zero growth in 30 years.

For the government deficit, \( \Delta G \), we set it at the current 1.5% of GDP initially, declining steadily towards zero in the long run. These deficits are cumulated into the stocks of debt, \( B_t \) and \( B^G_t \), assuming a constant division between domestic and foreign borrowing. Data for the stock of debt and interest paid on it comes from World Bank (1995, 1996) and State Statistical Bureau (1996). Government investment expenditures and transfers are determined by the \( \gamma^f \) and \( \gamma \) coefficients. We set them to the shares in the latest available year as given in the SAM in Figure 2, and keep them fixed for the whole projection period. Similarly, \( \gamma^N \) is set and fixed.

The supply of land for agriculture and mining is simply set fixed for all periods equal to the base year value. This is not entirely satisfactory, but improvements on this must await estimates of the cost of clearing land and cost of oil and gas exploration. Also, as we have noted, the data on land

\(^{11}\) E.g. Ezaki and Jorgenson (1973) calculated that the quality of the total capital stock was rising at 3% per annum in Japan for the period 1951-68. This “quality” does not refer to the everyday notion of one year’s machinery being better than the previous year’s which is taken into account by a proper measurement of the price of capital.
for the real estate sector is still lacking.

The current account balance as a share of GDP has been close to balance in the last few years after years of large deficits in the early 1990s. We set it at the observed 1995 value for the initial year and set to zero for the other years. This CA is, of course, also the assumed rate of borrowing from the world. Import prices, \( PM^*_i \), with the exception of oil prices, are normalized to 1 and kept fixed for every period. Forecasts of world oil prices are taken from the U.S. Dept. of Energy (EIA 2000), which projects a very slow rise (0.2% per annum) in the relative price of oil for 2000-2020.

The model also requires estimates of world demand for Chinese exports, \( EX_{it} \). In line with recent Chinese experience, and the Japanese experience of the 60s, we project a high rate of growth of exports, beginning at a 7% growth rate and falling to 2% in 30 years.

Local Pollution and Health Coefficients

The emission factors and health effects that appear in eqs. (152-157) comes in part from World Bank (1997) and Lvovsky and Hughes (1997). We employ their base coefficients and adjust to the 1995 emission data in the China Environmental Yearbook. That is, we scaled the \( \sigma_{jx} \) and \( \psi_{jxf} \) coefficients from Lvovsky and Hughes in (152) so that they equal the emission data when applied to the outputs and fuel inputs of 1995 that we derive from our SAM. We also aggregated their emission-to-concentration equations, which were indexed by cities, producing the national equation in (155). The updated population data (total and urban) comes from State Statistical Bureau (1999).

Parameters.

As discussed in section 2 of HJP there is some disagreement about the magnitude of recent Chinese productivity growth. We estimate that for GDP the combined effect of capital quality, labor quality and productivity to have been growing at a 3% annual rate in the 1978-92 period. In our projections of the sectoral productivity terms in eq. (19) we chose to set all the \( \mu \)'s to the same value, \( \mu = 0.03 \) and \( \alpha_{1j}^t = -0.015 \).

The value share parameters of the production functions, \( \alpha_{Kt}, \alpha_{Et}, \) etc., are set to the values in the 1995 IO table in the first year of the simulation. For future periods we change these parameters so that they gradually resemble the shares found in the US input output table for 1982. Garbaccio, Ho and Jorgenson (1999) discusses the actual change in energy use between 1987 and 1992 in greater detail. We find that the quantity of energy use per unit of output for most of the 30 sectors have fallen, however, the value share shows a more mixed pattern. In other words, the fall in energy inputs has been due in part to an increase in the prices of coal, oil and electricity. If all the change in input is attributed to price effects than the elasticity is not quite one as implied by the Cobb-Douglas function but close. We shall be more explicitly dynamic in the specification of \( \alpha_{Et} \) coefficients in
future versions of the model. The remaining parameters of the production function, \( \alpha_i^E, \alpha_i^M \) are also set to gradually approach the US 1982 values. The exceptions to this are the coal inputs for all the sectors, this is set to converge to a level higher than US1982.

The \( \alpha_{it}^C \) parameters of the consumption function are set in a similar way. That is, for the first period they are equal to the shares in the 1995 input output table, and for the future periods they gradually approach US 1982 shares except for coal. This imply a higher projected demand for private vehicles and gasoline than that assumed in most other models of China.
Notation:

Time
\( t \in I_T \quad I_T = \{1, 2, \ldots, T, \ldots\} \)

Industry/Producer
\( j \in I_{IND} \quad I_{IND} = \{1, 2, \ldots, N\} \)

IO Commodities
\( i \in I_{COM} \quad I_{COM} = \{1, 2, \ldots, N\} \)

Purchasers of domestic output
\( j \in I_{BUY} \quad I_{BUY} = \{1, 2, \ldots, 30, C, J, G, X\} \)

Nodes of production function
\( m \in I_{PNODE} \quad I_{PNODE} = \{EN, M\} \)
\( i \in I_{PNODE}^m \)

Externalities
\( x \in I_{EXT} \quad I_{EXT} = \{CO_2, TSP, SO_2, \ldots\} \)
\( c \in I_{HT} \quad I_{HT} = \{low, medium, high\} \)
\( p \in I_{PEXT} \quad I_{PEXT} = \{\text{waste water, waste gas, solid}\} \)
\( f \in I_{FUEL} \quad I_{FUEL} = \{\text{coal, oil, gas}\} \)
\( h \in I_{HEALTH} \quad I_{HEALTH} = \{\text{mortality, respiratory hospital admis., Emergency room visits, restricted activity days, lower respiratory infection, asthma attacks, chronic bronchitis, respiratoty symptoms (TSP), chest discomfort, respiratory systems (SO2)}\} \)

Market and plan variables
\( x, \dot{x}, \bar{x} \quad \text{Total, market, plan } x \)

Transpose of matrix A
\( A' \)

Diagonal matrix of a vector \( v \)
\( \text{Diag}(v) \)
12.1 Values and Other Variables:

- $A_{ij}$ \( i \in I_{COM}, j \in I_{IND} \): Share of input $i$ in producing output $j$
- $B^*$: Net Chinese private sector debt to rest-of-world
- $B^{G*}$: Government debt to rest-of-world
- $CA$: Current account surplus of China
- $CF(K_j)$ \( j \in I_{IND} \): Cash Flow to industry $j$
- $Damage_h$ \( h \in I_{HEALTH} \): Value of damage due to health effect $h$
- $DIV$: Dividend income (total distributed profits)
- $EX_{it}$ \( i \in I_{COM} \): Exogenous projected exports.
- $G_{-I}$: Govt interest payments on public debt to households
- $G_{-IR}$: Government interest payments to rest-of-world
- $G_{-INV}$: Government payments for investment by enterprises
- $G_{-SUBSID}$: Government subsidies (negative sales tax)
- $G_{-transfer}$: Government transfers to households
- $GFB$: Government foreign borrowing
- $GENT$: Government transfers to enterprises
- $NFY$: Net factor income to rest-of-world
- $RE$: Retained earnings of enterprises
- $R_{-CON}$: Revenue from consumption tax
- $R_{-EXT}$: Revenue from externalities/pollution tax
- $R_{-K}$: Revenue from taxes on capital income
- $R_{-L}$: Revenue from taxes on personal (labor) income
- $R_{-SALES}$: Revenue from sales tax
- $R_{-TARIFF}$: Revenue from import tariffs
- $R_{-REBATE}$: Rebate on VAT for exports
- $R_{-transfer}$: Rest-of-world transfer to Households
- $R_{-VAT}$: Revenue for value added tax
- $SD$: Vector of shares of domestic goods in total supply
- $SI^m$ \( m \in I_{INV} \): Shares of investment at node $m$
- $SM$ \( i \in I_{COM} \): Import share of commodity $i$
- $SP^{jm}$ \( j \in I_{IND}, m \in I_{pnode} \): Shares of production at node $m$ of industry $j$
- $Sp$: Private Savings
- $TD$: Value of total health damage
TLUMP  Lump sum tax
TAXN\textsuperscript{hh}  Non-tax payments from households to government
TAXN\textsuperscript{ent}  Non-tax payments from enterprises to government
TR\textsuperscript{C}  Implicit transfers to household due to plan prices
TR\textsuperscript{I}  Implicit transfers to investors due to plan prices
TR\textsubscript{j}  Implicit transfers to firms (plan output price)
TR\textsubscript{j}\textsuperscript{O}  Implicit transfers from firms (plan output price)
TR\textsubscript{j}\textsuperscript{L}  Implicit transfers to firms (plan labor price)
TR\textsubscript{j}\textsuperscript{I}  Implicit transfers to firms (plan input price)
VC  Vector of values of household purchases of commodities
VFD  Vector of values of final demand for commodities
VG  Vector of values of government demand for commodities
VGG  Value of government purchases
VII  Value of domestic private investment
VI  Vector of values of investment inputs
VP\textsubscript{j}  Vector of values of inputs into industry j
VQC  Vector of values of domestic commodity output
VQI  Vector of values (to producer) of domestic industry output
VQI\textsubscript{t}  Vector of values of domestic industry output inclusive of sales tax
VQS  Vector of values of total commodity supply
VX  Vector of values of commodity exports
W\textsuperscript{p}  Tangible private wealth of households
Y\textsuperscript{p}  Private income of households
Y(\textit{LS})  Labor income after taxes
\Delta G  Government deficit
12.2 Quantities:

$CC$ Aggregate consumption (commodities)
$C$ Vector of consumption
$C_i, ar{C}_i$ Consumption of IO commodity $i$; total, plan
$CN_k$ Consumption of aggregate $k$
$C^N_x$ National Concentration of $x$ in $\mu g/m^3$
$E_{cx}$ Emissions of $x$ at height $c$
$EM_{jx}$ Emissions of $x$ from sector $j$
$\text{emission}$ Amount of $CO_2$ in tons of carbon

$\text{energy}$ Amount of primary energy consumed (tons SCE)

$EXT_x$ Quantity of externality $x$ generated by use of inputs
$\text{EXT}_x$ e.g. carbon dioxide from burning fuels

$EXT\_P_p$ Quantity of externality $p$ generated through production
$\text{EXT}\_P_p$ e.g. waste water from industrial production, household sewage

$G$ Vector of government purchases
$G_i$ Government purchases of commodity $i$ (Social Cons.)
$HE_h$ Health effect of type $h$
$I^a, \bar{I}^a$ Aggregate investment in domestic capital stock; total, market.

$I$ Vector of commodities used in aggregate investment.
$I^f_i$ Investment of commodity $i$ in fixed investment
$I_i, \bar{I}_i$ Investment of commodity $i$ in domestic $K$; total, market
$\bar{K}_i$ Capital stock (market portion) located in China
$KD_j, \bar{KD}_j$ Quantity of capital input into $j$; total, market
$LD_j, \bar{LD}_j$ Quantity of labor input in $j$; market, plan
$LH$ Time endowment of economy
$LS$ Labor supply

$M$ Vector of imports.
$M_i$ Imports of commodities
$N_j$ No. of workers in $j$
$POP^w$ Working age Population
$POP^u$ Urban Population

$QC_i$ Total domestic output of commodity $i$
$QI_j$ Output of industry $j$
$QP_{jm}$ Aggregate input $m$ into industry $j$
$QP_{ij}$ Input of commodity $i$ in indus. $j$; total, plan
$QS_i$ Total supply of commodity $i$
$T_i$ Land available for agri; oil mining
$TD_j$ Demand for land inputs
$X$ Vector of exports.
$X_i$ Exports of commodity $i$
12.3 Prices:

\( e \)

"exchange rate"

\( i* \)

interest rate payable to rest-of-world

\( r_j \)

After tax rate of return from \( j \)

\( r \)

Rate of return of aggregate market capital

\( p_{LEIS} \)

Price of leisure

\( \dot{P}_i \)

Plan price of output \( i \)

\( P_{i*} \)

World price for Chinese exports.

\( P_{i}^{C} \)

Price of Consumer commodity

\( P_{Pj,m} \)

Vector of prices at node \( m \) of industry \( j \)'s production function

\( PC_i \)

Price of domestically produced commodities

\( PI_j \)

Price of industry output paid by buyers

\( PI_{I}^a \)

Price of aggregate investment goods

\( PI_{I}^f \)

Price of aggregate fixed investment

\( PI_{I}^i \)

Price of aggregate inventory investment

\( PK \)

Price of aggregate capital stock

\( PK_{Dj} \)

Rental price of capital paid by producer

\( PK_{Dj}^t \)

Rental price of capital after VAT, before \( tk \)

\( PL_{ij}, PL_{j} \)

Price of labor paid by employers; market, plan

\( PL_{j} \)

Price of labor received by workers after VAT, before \( tl \)

\( PM_{i} \)

Price of non-competitive imports paid by importers

\( PN_k \)

Price of consumption aggregate \( k \)

\( PO_j \)

Price of industry output received by producer

\( PP_{j,m} \)

Price of aggregate input \( m \) into industry \( j \)

\( PP_{mi} \)

Union of above set of aggregate production prices and prices of inputs.

\( PS \)

Vector of supply prices.

\( PS_{i} \)

Price of commodities to buyers

\( PT_{i} \)

Rental price of land
12.4 Parameters and coefficients:

\[ \alpha \] Reference concentration of pollution from WHO

\[ \alpha^C_{k} \quad k \in I_{\text{CNODE}} \] Shares (at unit prices) of consumption at node k

\[ \alpha^0_j \quad j \in I_{\text{IND}} \] Cost function constant

\[ \alpha^{P_{jm}}_j \quad j \in I_{\text{IND}} \quad m \in I_{\text{PNODE}} \] Shares (at unit prices) of of inputs into industry j at node m

\[ B^{P_{jm}}_j \] Share elasticity of input demands (w.r.t. prices) at node m

\[ \mu_j \] Slope of exponential curve representing index of technology

\[ \alpha_j^f \quad i \in I_{\text{INP}} \] Share of fixed investment in total investment

\[ \alpha_i^f \quad i \in I_{\text{INP}} \] Shares of commodities in Fixed Investment

\[ \alpha_i^I \quad i \in I_{\text{INP}} \] Shares of commodities in Inventory Investment

\[ \alpha_i^G \quad i \in I_{\text{INP}} \] Share of government expenditures on i

\[ \gamma \] Coefficient for govt direct transfers

\[ \gamma^{Nhh} \] Household nontax payments as share of GDP

\[ \gamma^{Net} \] Enterprise nontax payments as share of GDP

\[ \gamma^I \] Share of total investment paid directly by govt.

\[ \gamma_{ex} \quad c \in I_{\text{HT}}, \ x \in I_{\text{EXT}} \] Emission to concentration factor

\[ \beta_i \quad i \in I_{\text{COM}} \] Elasticity of imports

\[ \eta^i \quad i \in I_{\text{COM}} \] Export price elasticities

\[ \delta \] Rate of depreciation of capital stock

\[ \psi^K \] Aggregation constant of capital services

\[ \psi_j^K \quad j \in I_{\text{BUY}} \] Aggregation constant of capital services

\[ \psi_j^L \quad j \in I_{\text{BUY}} \] Aggregation constant of labor

\[ \psi_j^G \] Aggregation constant of investment goods

\[ \psi^{PK} \] Aggregation constant of price of capital

\[ \psi_j^{xf} \quad f \in I_{\text{FUEL}} \] Emission factor of pollutant x from fuel f

\[ \sigma_{jx} \] Process emission factor of pollutant x

\[ d_i \quad m_i \quad i \in I_{\text{COM}} \] Shares of domestic commodities and imports in total supply

\[ DR_{hx} \quad h \in I_{\text{HEALTH}} \] Dose response of effect h due to increase in conc of x.

\[ er \] Exposure rate (share of population exposed to \( C^N_x \))

\[ M \] IO Make matrix; the contribution of each industry to each commodity

\[ V_h \quad h \in I_{\text{HEALTH}} \] Willingness-to-pay value of health effect h

\[ XP_{jp} \quad p \in I_{\text{PEXT}} \] Production externality of p per unit of output j

\[ XM_{ix} \quad x \in I_{\text{EXT}} \] Externality of x per unit of import i used

\[ XU_{ix} \quad x \in I_{\text{EXT}} \] Externality of x per unit of commodity i used
12.5 Tax rates:

- $t_{ci}$, $i \in I_{COM}$: Consumption tax rate on commodity i
- $tk$: Tax rate on capital income
- $tk^f$: Tax rate on capital income from financial assets
- $tl^a$: Average tax(subsidy) rate on labor income
- $tl^m$: Marginal tax(subsidy) rate on labor income
- $tr_i$, $i \in I_{COM}$: Tariff rate on competitive imports
- $tv_j$, $j \in I_{IND}$: Value added tax rate
- $se_i$, $i \in I_{COM}$: VAT rebate for exports
- $tr^*_i$, $i \in I_{COM}$: World tariff rate on China exports
- $tt_j$, $j \in I_{IND}$: Sales tax on domestic output
- $ts_j$, $j \in I_{IND}$: Sales subsidy on domestic output
- $tx_{X^v}$: Tax on one Yuan of externality x
- $tx_{X^u}$: Tax on one unit of externality x
- $tx^i_U$: Externality tax rate per unit of commodity i
- $tx^i_Y$: Externality tax rate per Yuan of commodity i
- $tx^u_U$: Externality tax rate per unit of import i
- $tx^u_Y$: Externality tax rate per Yuan of import i
- $tp^p$: Tax on the production of one unit of pollutant p
- $tp^p_j$: Total pollution taxes per unit of industry j
13 References


Table 1: China Sectoral Characteristics, 1995.

<table>
<thead>
<tr>
<th>No.</th>
<th>Industry</th>
<th>Output</th>
<th>Energy Use</th>
<th>Capital</th>
<th>Labor</th>
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<td></td>
<td>bil. Y</td>
<td>mil. t SCE</td>
<td>bil. Y</td>
<td>mil.</td>
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Source: Input-output Table of China, authors calc.
Table 2: Emissions and height classification, 1995.

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<th>SO2 (ktons)</th>
<th>Emission Height</th>
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Source: Emissions for industrial sectors come from China Environmental Yearbook; for the nonindustrial sectors we make estimates from summary data.
Table 3: Dose-response and valuation estimates for PM10 and SO2

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<tr>
<th>Health Effects</th>
<th>Cases per mil. per $\mu g/m^3$</th>
<th>Valuation in 1995</th>
<th>Valuation in 1995</th>
<th>Valuation in 2020</th>
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<td>12.00</td>
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<td>2,930</td>
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<td>3 Emergency room visits</td>
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<td>140</td>
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<td>86</td>
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<td>4 Restricted activity days (days)</td>
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<td>7 Chronic bronchitis</td>
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<td>8 Respiratory symptoms</td>
<td>183,000.00</td>
<td>50</td>
<td>9</td>
<td>31</td>
</tr>
<tr>
<td>Due to SO2:</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>9 Chest discomfort</td>
<td>10,000.00</td>
<td>50</td>
<td>9</td>
<td>31</td>
</tr>
<tr>
<td>10 Respiratory systems/child</td>
<td>5.00</td>
<td>50</td>
<td>9</td>
<td>31</td>
</tr>
</tbody>
</table>

Source: Dose responses are from World Bank (1997) updated. Valuations in US$ are from Lvovsky and Hughes (1997). Valuation in Yuan are authors’ estimates.