Appendix A: Economic-Environmental Model of China (version 18); ETS-Hybrid tax application

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February 12 2019

This description of the Model updates the one given in *Clearer Skies over China* (Nielsen and Ho eds. 2013).

In this appendix we describe the economic-environment model for China in some detail, beginning with the modeling of each of the main economic agents in section A.1. Then in section A.2 we describe the data and parameters underlying the model. A previous version of this model of the Chinese economy is used in Ho and Nielsen (2013) and here we describe the updates to it. This is a multi-sector model of economic growth where the main drivers of growth are investment, population, total factor productivity growth and changes in the quality of labor and capital. It has a dynamic recursive structure, i.e. where investment is determined by fixed savings rate as in the Solow model. Consumption demand is driven by a translog household model that distinguishes demand by different demographic groups.

A.1 Structure of Model

We discuss the five main actors in the economy in turn – producers, households, capital owners, government and foreigners. For easy reference Table A1 lists variables which are referred to with some frequency. In general, a bar above a symbol indicates that it is a plan parameter or variable while a tilde indicates a market variable. Symbols without markings are total quantities or average prices. To reduce unnecessary notation, we drop the time subscript, *t*, from our equations whenever possible.

A.1.1. Production

The 33 industries identified in the model are given in Table A3 together with their output, value added and number of workers in the base year 2014. Each of the 33 industries is assumed to produce its output using a constant returns to scale technology. For each sector *j* the output at time t, QI_{jt}, is expressed as:

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

where KD_j, LD_j, TD_j, and A_{ij} are capital, labor, land, and intermediate inputs, respectively.[1] In sectors for which both plan and market allocation exists, output is made up of two

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

components, the plan quota output ($\overline{QI}_j$) and the output sold on the market ($\tilde{QI}_j$). The plan quota output is sold at the state-set price ($\overline{PI}_j$) while the output in excess of the quota is sold at the market price ($\tilde{PI}_j$). The *PI* and *QI* names are chosen to reflect that these are domestic industry variables, as opposed to commodities (*PC*) or total supply (*PS*), the sum of domestic commodities and imports. For most commodities, all buyers pay the same price $\tilde{PS}_i$, however, we allow some goods to have buyer specific taxes, for example, carbon permits only required of sectors covered by an emission trading system. In that case, the buyer-specific price is denoted by, PB_{ij}.

A more detailed discussion of how this plan-market formulation is different from standard market economy models is given in Garbaccio, Ho, and Jorgenson (1999). In summary, if the constraints are not binding, then the "two-tier plan/market" economy operates at the margin as a market economy with lump sum transfers between agents. The capital stock in each industry consist of two parts – the fixed capital, $\overline{K}_j$, that is inherited from the initial period, and the market portion, $\tilde{KD}_j$, that is rented at the market rate. The before-tax return to the owners of fixed capital in sector *j* is:

$$\text{(A2)} \qquad profit_j = \overline{PI}_j\,\overline{QI}_j + \tilde{PI}_j\,\tilde{QI}_j - \tilde{P}_j^{KD}\tilde{KD}_j - PL_jLD_j - PT_jTD_j$$
$$- \sum_i \overline{PB}_{ij}\,\overline{A}_{ij} - \sum_i \tilde{PB}_{ij}\,\tilde{A}_{ij} \qquad .$$

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

We represent the production structure with the cost dual, expressing the output price as a function of input prices and an index of technology. The 3 primary factors and 33 intermediate inputs for each industry are determined by a nested series of constant elasticity of substitution (CES) functions taken from the GTAP model (version 7). The nest structure is given in Figure 1.

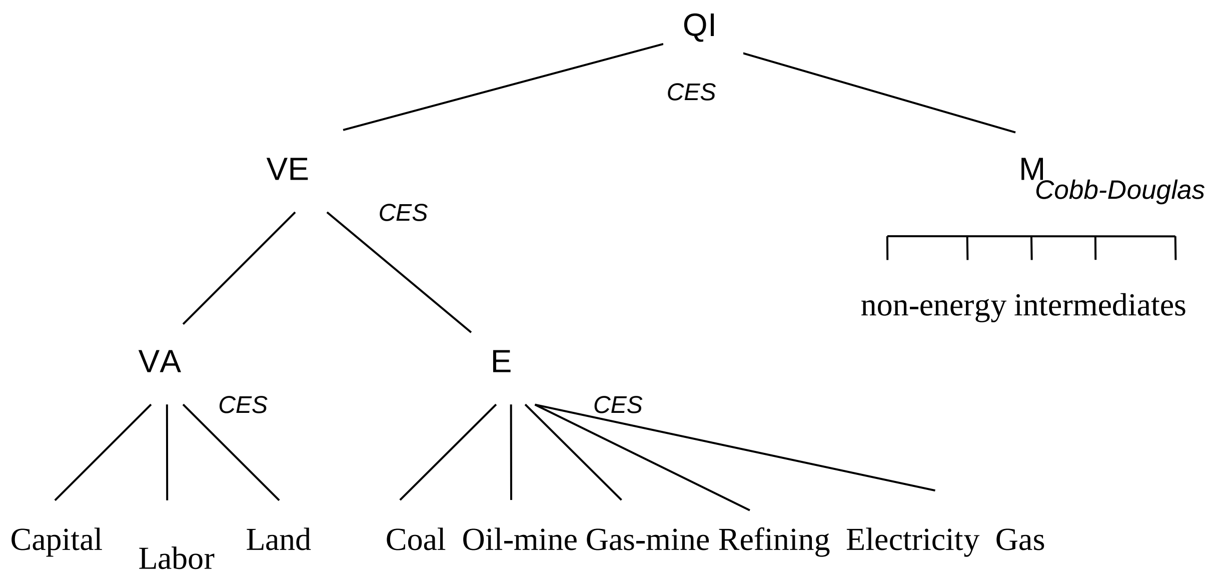

Figure 1. Production structure.

At the top tier, output is a function of the primary factor-energy basket (VE) and the non-energy intermediate input basket (M), $QI_{jt} = f(VE_{jt}, M_{jt}, t)$. The VE basket is an aggregate of value added (VA) and the energy basket (E). Value added is a function of the 3 primary factors – capital (K), labor (L) and land (T). The energy aggregate is a CES function of coal, oil mining, gas mining, petroleum refining & coal products, electricity and gas commodities. The materials aggregate (M) is a Cobb-Douglas function of the 27 non-energy commodities.

The top tier value equation and cost function are, respectively,:

(A3) $$PI_{jt} QI_{jt} = P_{jt}^{VE} VE_{jt} + PM_{jt} M_{jt}$$

(A4) $$PI_{jt} = \frac{\kappa_{jt}^{QI}}{g_{jt}} \left[\alpha_{Mjt}^{\sigma_{jt}^{QI}} PM_{jt}^{\left(1-\sigma_{jt}^{QI}\right)} + \left(1 - \alpha_{Mjt}\right)^{\sigma_{jt}^{QI}} P_{jt}^{VE\left(1-\sigma_{jt}^{QI}\right)} \right]^{\frac{1}{1-\sigma_{jt}^{QI}}}$$

where α_{Mj} is the weight for all non-energy inputs into industry *j*, and $1/\sigma_{jt}^{QI}$ is the elasticity of substitution between the two inputs. g_{jt} is the index of the level of technology where a rising value indicates positive TFP growth and falling output prices. This index of technology may be set to follow a smooth function, or calibrated discretely to hit some targeted exogenous GDP growthpatj. As an example, we may set the growth to follow an exponential pattern: $\dot{g}_j(t) = A_j \exp(-\mu_j t)$, which implies a technical change that is rapid initially, but gradually declines toward zero.

The primal function corresponding to the above cost dual is:

$$\text{(A5)} \quad QI_{jt} = \frac{g_{jt}}{\kappa_{jt}^{QI}} \left[\alpha_{Mjt} M_{jt}^{\frac{\sigma_{jt}^{QI}-1}{\sigma_{jt}^{QI}}} + \left(1 - \alpha_{Mjt}\right) VE_{jt}^{\frac{\sigma_{jt}^{QI}-1}{\sigma_{jt}^{QI}}} \right]^{\frac{\sigma_{jt}^{QI}}{\sigma_{jt}^{QI}-1}}$$

The input demands derived from the CES cost function are:

$$\text{(A6)} \quad VE_{jt} = \left(\frac{\kappa_{jt}^{QI}}{g_{jt}} \right)^{1-\sigma_{jt}^{QI}} \left[\left(1-\alpha_{Mjt}\right) \frac{PI_{jt}}{P_{jt}^{VE}} \right]^{\sigma_{jt}^{QI}} QI_{jt}$$

$$M_{jt} = \left(\frac{\kappa_{jt}^{QI}}{g_{jt}} \right)^{1-\sigma_{jt}^{QI}} \left[\alpha_{Mjt} \frac{PI_{jt}}{PM_{jt}} \right]^{\sigma_{jt}^{QI}} QI_{jt}$$

The weights for the CES functions are explained in Rutherford (2003) and Klump, McAdam and Willman (2011); these weights are calibrated using the base year values:

$$\text{(A7)} \quad \alpha_{Mj0} = \frac{PM_{j0} M_{j0}^{1/\sigma_{jt}^{QI}}}{P_{j0}^{VE} VE_{j0}^{1/\sigma_{jt}^{QI}} + PM_{j0} M_{j0}^{1/\sigma_{jt}^{QI}}} \; ; \; \frac{g_{j0}}{\kappa_{j0}^{QI}} = QI_{j0} / \left[\alpha_{Mj0} M_{j0}^{\frac{\sigma_{jt}^{QI}-1}{\sigma_{jt}^{QI}}} + \left(1-\alpha_{Mj0}\right) VE_{j0}^{\frac{\sigma_{jt}^{QI}-1}{\sigma_{jt}^{QI}}} \right]^{\frac{\sigma_{jt}^{QI}}{\sigma_{jt}^{QI}-1}}$$

The corresponding equations for the primary factor-energy basket and the value-added basket are:

$$\text{(A8)} \quad \begin{aligned} P_{jt}^{VE} VE_{jt} &= P_{jt}^{VA} VA_{jt} + PE_{jt} E_{jt} \\ P_{jt}^{VA} VA_{jt} &= P_{jt}^{KD} KD_{jt} + PL_{jt} LD_{jt} + PT_{jt} TD_{jt} \end{aligned}$$

$$\text{(A9)} \quad P_{jt}^{VE} = \frac{1}{\kappa_{jt}^{VE}} \left[\alpha_{Ejt}^{\sigma_{jt}^{VE}} PE_{jt}^{\left(1-\sigma_{jt}^{VE}\right)} + \left(1 - \alpha_{Ejt}\right)^{\sigma_{jt}^{VE}} P_{jt}^{VA\left(1-\sigma_{jt}^{VE}\right)} \right]^{\frac{1}{1-\sigma_{jt}^{VE}}}$$

$$\text{(A10)} \quad P_{jt}^{VA} = \frac{1}{\kappa_{jt}^{VA}} \left[\alpha_{Kjt}^{\sigma_{jt}^{VA}} P_{jt}^{KD\left(1-\sigma_{jt}^{VA}\right)} + \alpha_{Ljt}^{\sigma_{jt}^{VA}} PL_{jt}^{\left(1-\sigma_{jt}^{VA}\right)} + \left(1-\alpha_{Kjt}-\alpha_{Ljt}\right)^{\sigma_{jt}^{VA}} PT_{jt}^{\left(1-\sigma_{jt}^{VA}\right)} \right]^{\frac{1}{1-\sigma_{jt}^{VA}}}$$

$$(A11)\quad VA_{jt} = \left(\frac{1}{\kappa_{jt}^{VE}}\right)^{1-\sigma_{jt}^{VE}} \left[\left(1-\alpha_{Ejt}\right)\frac{P_{jt}^{VE}}{P_{jt}^{VA}}\right]^{\sigma_{jt}^{VE}} VE_{jt}$$

$$E_{jt} = \left(\frac{1}{\kappa_{jt}^{VE}}\right)^{1-\sigma_{jt}^{VE}} \left[\alpha_{Ejt}\frac{P_{jt}^{VE}}{PE_{jt}}\right]^{\sigma_{jt}^{VE}} VE_{jt}$$

$$(A12)\quad KD_{jt} = \left(\frac{1}{\kappa_{jt}^{VA}}\right)^{1-\sigma_{jt}^{VA}} \left[\alpha_{Kjt}\frac{P_{jt}^{VA}}{P_{jt}^{KD}}\right]^{\sigma_{jt}^{VA}} VA_{jt} \qquad TD_{jt} = \left(\frac{1}{\kappa_{jt}^{VA}}\right)^{1-\sigma_{jt}^{VA}} \left[\alpha_{Tjt}\frac{P_{jt}^{VA}}{PT_{jt}}\right]^{\sigma_{jt}^{VA}} VA_{jt}$$

$$LD_{jt} = \left(\frac{1}{\kappa_{jt}^{VA}}\right)^{1-\sigma_{jt}^{VA}} \left[\alpha_{Ljt}\frac{P_{jt}^{VA}}{PL_{jt}}\right]^{\sigma_{jt}^{VA}} VA_{jt}$$

The parameters are calibrated to base year values:

$$(A13)\quad \alpha_{Ej0} = \frac{PE_{j0}E_{j0}^{1/\sigma_{jt}^{VE}}}{P_{j0}^{VA}VA_{j0}^{1/\sigma_{jt}^{VE}} + PE_{j0}E_{j0}^{1/\sigma_{jt}^{VE}}}\ ;\ \ \kappa_{j0}^{VE} = VE_{j0}/[\alpha_{Ej0}E_{j0}^{\frac{\sigma_{jt}^{VE}-1}{\sigma_{jt}^{VE}}} + \left(1-\alpha_{Ej0}\right)VA_{j0}^{\frac{\sigma_{jt}^{VE}-1}{\sigma_{jt}^{VE}}}]^{\frac{\sigma_{jt}^{VE}}{\sigma_{jt}^{VE}-1}}$$

$$\alpha_{Kj0} = \frac{P_{j0}^{KD}KD_{j0}^{1/\sigma_{jt}^{VA}}}{P_{j0}^{KD}KD_{j0}^{1/\sigma_{jt}^{VA}} + P_{j0}^{LD}LD_{j0}^{1/\sigma_{jt}^{VA}} + P_{j0}^{TD}TD_{j0}^{1/\sigma_{jt}^{VA}}}\ ;\ \alpha_{Lj0} = \ldots;\ \alpha_{Tj0} = \ldots$$

$$\kappa_{j0}^{VA} = VA_{j0}/[\alpha_{Kj0}KD_{j0}^{\frac{\sigma_{jt}^{VA}-1}{\sigma_{jt}^{VA}}} + \alpha_{Lj0}LD_{j0}^{\frac{\sigma_{jt}^{VA}-1}{\sigma_{jt}^{VA}}} + \left(1-\alpha_{Kj0}-\alpha_{Lj0}\right)TD_{j0}^{\frac{\sigma_{jt}^{VA}-1}{\sigma_{jt}^{VA}}}]^{\frac{\sigma_{jt}^{VA}}{\sigma_{jt}^{VA}-1}}$$

Note that the cost functions for the sub-aggregates do not have an index of technology; however, the share coefficients – $\alpha_{Ejt}, \alpha_{Kjt}$, etc. – are allowed to change over time to reflect biases in technical change.

The energy basket equations give the demands for the 6 types of energy by industry *j*. For energy policies we allow for sector specific taxes, i.e. having different buyers pay a different price for input *k*:

$$(A14)\quad PE_{jt}E_{jt} = \sum_{k\in IE} PB_{kjt}A_{kjt}$$

$$(A15)\quad PE_{jt} = \frac{1}{\kappa_{jt}^{E}}\left[\sum_{k\in IE}\alpha_{kjt}^{E\sigma_{jt}^{E}} PB_{kjt}^{\left(1-\sigma_{jt}^{E}\right)}\right]^{\frac{1}{1-\sigma_{jt}^{E}}} \qquad \text{IE=\{coal, oil, gasmine, refine, elect, gas\}}$$

$$A_{kjt} = \left(\frac{1}{\kappa^E_{jt}}\right)^{1-\sigma^E_{jt}} \left[\alpha^E_{kjt} \frac{PE_{jt}}{PB_{kjt}}\right]^{\sigma^E_{jt}} E_{jt} \qquad k \in IE$$

$$\alpha^E_{kj0} = \frac{PB_{kj0} A^{1/\sigma^E_{jt}}_{kj0}}{\sum_{i\in IE} PB_{ij0} A^{1/\sigma^E_{jt}}_{ij0}}; \quad \kappa^E_{j0} = E_{j0} / [\sum_{k\in IE} \alpha^E_{kj0} A_{kj0}^{\frac{\sigma^E_{jt}-1}{\sigma^E_{jt}}}]^{\frac{\sigma^E_{jt}}{\sigma^E_{jt}-1}}$$

The non-energy input basket is a Cobb-Douglas function of the remaining non-energy sectors (denoted NE; 33-6=27 components), and the corresponding equations are:

(A16) $\ln PM_{jt} = \sum_{k\in NE} \alpha^M_{kjt} \ln PS_{kt}$ NE={agri, … , services, admin}

$$PM_{jt} M_{jt} = \sum_{k\in NE} PS_{kt} A_{kjt}$$

$$A_{kjt} = \alpha^M_{kjt} \frac{PM_{jt} M_{jt}}{PS_{kt}} \quad k \in NE$$

For this non-energy inputs, we assume that there are no buyer-specific taxes, and all sectors pay the same price, PS_{kt}.

We set the energy share α_{Ej} to fall gradually over the next 40 years while the labor coefficient, α_{Lj}, rises correspondingly. The composition of the aggregate energy input E_j (i.e. the α^E_{kj} coefficients) are also allowed to change over time.

Distinction between firms within an industry

Some policies in China distinguish between large and small enterprises, for example, the CO2 Emissions Trading System requires emission permits only for those enterprises emitting more than 26,000 tons of CO2-equivalent per year. Analysis of these policies requires a distinct treatment of enterprises covered by the policy compared to the "uncovered" firms within an industry in the model. We allow for this by dividing industry output into two components with their own cost functions and input prices. Industry output in the set I_{cov} is thus the sum of the covered and uncovered parts; and we allocate them using exogenous shares:

(A17) $QI_{jt} = QI^C_{jt} + QI^U_{jt}$; $\qquad j \in I_{\text{cov}}$

$$QI_{jt}^{C} = \lambda_{jt}^{\text{cov}} QI_{jt}$$

The political-economy process will largely determine these shares and a policy preference to nudge the system towards a particular part can be incorporated by changing these $\lambda_{jt}^{\text{cov}}$'s over time.

Each of the components, QI_{jt}^{C} and QI_{jt}^{U}, will have their own versions of eqs. (A3-A12), in particular, they may face different input prices. This will result in two prices for their output: PI_{jt}^{C} and PI_{jt}^{U}. Since we are assuming that the two outputs are perfectly substitutable from the user point of view, the price to the buyer of industry j's output is the average price, PI_{jt}:

(A18) $PI_{jt} QI_{jt} = PI_{jt}^{C} QI_{jt}^{C} + PI_{jt}^{U} QI_{jt}^{U}$; $\qquad j \in I_{\text{cov}}$

Industries versus Commodities; Output taxes

There are taxes and subsidies on industry gross output (or sales tax) and we represent the net value by the ad-valorem tax rate, t_j^t. A negative value represents a net subsidy. In China there are "resource taxes" that are placed on extraction industries such as coal and oil mining, and we recognize them separately with rate t_j^{res}. We may also have counterfactual (policy) externality taxes which may be either ad-valorem (t_i^x) or on unit output (e.g. per ton of coal), t_i^{xu}. There may be taxes on process emissions t_j^{xpu} (see eq. A46b). The subsidy to output due to carbon policies is represented by s_{jt}^{CO2} (see eq. A56). The price to buyers of industry output (PI_j^t) is thus:

(A19) $PI_j^t \;=\; (1 + t_j^t + t_j^{res} + t_j^x) PI_j \;+\; t_j^{xu} + t_j^{xpu} - s_{jt}^{CO2}$

$PI_j^t \;=\; (1 + t_j^t + t_j^{res} + t_j^x - s_{jt}^{CO2}) PI_j \;+\; t_j^{xu} + t_j^{xpu}$ WRONG

The model distinguishes industries from commodities as in the official Use and Make input-output tables. Each industry may make a few commodities and each commodity may be made by a few industries; e.g. the Refining industry produces Refining commodity and Chemical commodity, and the Chemical commodity comes from Refining, Chemical, Primary Metal and other industries. The entry M_{ji}^{make} in the Make table gives the tax-inclusive yuan value of the *i*-th commodity produced by industry *j*. The total quantity of domestic commodity is denoted *QCi* and its price *PC*; the sum of column *i* in the Make matrix gives the value of commodity *i*, and the sum of row *j* is the industry output value. The relation between commodity and industry output and prices are written as:

(A20) $VQC_i = PC_i QC_i = \sum_j m_{ji}^r PI_j^t QI_j$

(A21) $\ln PC_i = \sum_j m_{ji}^c \ln PI_j^t$

where $m_{ji}^r = \frac{M_{ji}}{\sum_k M_{jk}}$ is the row share and $m_{ji}^c = \frac{M_{ji}}{\sum_k M_{ki}}$ is the column share for the *j*-th column.

A.1.2. Households

Private consumption in this model is driven by an aggregate demand function that is derived by aggregating over different household types. Each household derives utility from the consumption of commodities, is assumed to supply labor inelastically, and owns a share of the capital stock. It also receives income transfers from the government and foreigners (*G_transfer*, *R_transfer*), and receives interest on its holdings of public debt (G_*I*). Aggregate private income is the sum over all households, and this income, after taxes and the payment of various non-tax fees (*FEE*), is written as:

(A26) $Y^p = \sum_k y_k^p$

$$Y^p = YL + DIV + G\_I + G\_transfer + R\_transfer - FEE$$

DIV denotes dividend income (eq. A67b) and *YL* denotes aggregate labor income from supplying LS units of effective labor, less income taxes:

(A27) $YL = (1 - t^L) PL\, LS$.

The relationship between labor demand and supply is given in equation A33 below. Aggregate supply *LS* is a function of the working age population, average annual hours, and an index of labor quality:

(A28) $LS_t = POP_t^w \, hr_t \, q_t^L$.

DIV denotes dividends from the households' share of capital income and is explained below in A67. *G_I* and *G_transfer* represent interest and transfers from the government, and *R_transfer* is transfers from the rest-of-the-world.

Household income is allocated between consumption (VCC_t) and savings. In this model we use a simple Solow growth model formulation with an exogenous savings rate (s_t) to determine private savings (S_t^p):

(A29) $S_t^p = s_t Y_t^p = Y_t^p - VCC_t$.

Total consumption expenditures are allocated to the 33 commodities identified in the model. We do this with a demand function estimated over household consumption survey data. This consumption data is at purchaser's prices and follows the expenditure classification; these have to be linked later to the IO classifications and the factory-gate prices of the IO system. We arrange the demand system in a tier structure shown in Table 1. At the top tier total expenditures is allocated to Food, Consumer Goods, Housing and Services. In the sub-tiers these four bundles are allocated to 27 items.

Household *k*'s indirect utility function over the four aggregates in the top tier, $V(p,M_k)$, is of a form that allows for exact aggregation:

(A30) $\ln V_k = \alpha_0 + \ln(\frac{p_k}{M_k})'\alpha_p + \frac{1}{2}\ln(\frac{p_k}{M_k})'B\ln(\frac{p_k}{M_k}) + \ln(\frac{p_k}{M_k})'B_{pA}A_k$,

where M_k is the expenditures of household k, and $p = (p_{FD}^k, p_{CG}^k, p_{HS}^k, p_{SV}^k)'$ is the price vector of the 4 bundles. Each household type has its own distinct utility function and A_k is a vector of demographic dummy variables to indicate the size of the household, the presence of children, the age of the head, and the region. The budget constraint for household *k* is:

(A31) $M_k = \sum_i p_i^k c_i^k = p_{FD}^k c_{FD}^k + p_{CG}^k c_{CG}^k + p_{HS}^k c_{HS}^k + p_{SV}^k c_{SV}^k$

Table 1. Tier structure of household consumption

		Name	Components in Consumer Expenditures
1	C	Consumption	Food, Consumer goods, Services, Housing *CC =CC(FD, CG, SV, HS)*
2	FD	Food	Food & tobacco, Dining out $C^{FD} = C^{FD}$(C1, C2)
3	CG	Consumer goods	Clothing, Residential goods, Recreational & misc. goods, Vehicles & parts $C^{CG} = C^{CG}$(CL,RG,RM,C14)
4	SV	Services	Communication, Education, Recreational svc, Health, Other services, Imputations, Transportation $C^{SV} = C^{SV}$(C19,C22,C23,C24,C26,C27,TR)
5	HS	Housing	Rental & housing services, Utilities-Energy $C^{HS} = C^{HS}$(C5, *EN*)
6	CL	Clothing	Clothes-shoes, Clothing services $C^{CL} = C^{CL}$(C3, C4)
7	RG	Residential goods	Furniture, Appliances, Interior Decorations, HH daily-use articles $C^{RG} = C^{RG}$(C10, C11,C12,C13)
8	RM	Recreational & Misc. goods	Communications equip, Recreational articles, Books, Other goods $C^{RM} = C^{RM}$(C18, C20,C21,C25)
9	EN	Energy (dom)	Water, Electricity, Coal, Gas $C^{EN} = C^{EN}$(C6,C7,C8,C9)
10	TR	Transportation	Gasoline, Vehicle svcs, Transportation fees $C^{TR} = C^{TR}$(C15,C16,C17)

Let $w_i^k = p_i^k c_i^k / M_k$ denote the share of expenditure allocated to bundle i. Applying Roy's Identity we get the demand share vector:

(A32) $$w^k = \frac{1}{D(p_k)}(\alpha_p + B\ln\frac{p_k}{M_k} + B_{pA}A_k) = \frac{1}{D(p_k)}(\alpha_p + B\ln p_k - Bi\ln M_k + B_{pA}A_k)$$

where $D(p_k) = -1 + \iota' B_{pp} \ln p_k$ and $w^k = (w_{FD}^k, w_{CG}^k, w_{HS}^k, w_{SV}^k)'$.

The aggregate demand is obtained by summing over all household types. Let n_k be the number of households of type k; the aggregate share vector is then:

(A33)
$$w_t = \frac{\sum_k n_{kt} M_{kt} w_t^k}{\sum_k n_{kt} M_{kt}} = \frac{\sum_k n_{kt} M_{kt} w_t^k}{M_t}$$
$$= \frac{1}{D(p_t)} [\alpha_p + B \ln p_t - Bi \frac{\sum n_{kt} M_{kt} \ln M_{kt}}{M_t} + B_{pA} \frac{\sum n_{kt} M_{kt} A_k}{M_t}]$$
$$w_t = (\frac{p_{FDt}^{CE} c_{FDt}}{M_t}, \frac{p_{CGt}^{CE} c_{CGt}}{M_t} \frac{p_{SVt}^{CE} c_{SVt}}{M_t} \frac{p_{HSt}^{CE} c_{HSt}}{M_t})'$$

The above equations (A32) and (A33) are estimated simultaneously, with (A32) estimated over one year of cross-sectional consumer expenditure data, and (A33) estimated using time series national prices and aggregate consumption expenditures.

To use the estimated equation (A33) in the model that include projections into the future we make some modifications. Firstly, the consumer survey data does not include some items that are in the National Accounts such as imputed rentals for owner-occupied housing and FISIM. We make some adjustments to the α_p's to scale the shares to match the consumption in the Input-Output table for our base year 2014. We project the distribution and demographic terms to account for the aging impact and thus re-write the share demand system as:

(A34)
$$w_t = \frac{1}{D(p_t)} [\alpha_p + B \ln p_t - Bi (\sum n_{kt} \frac{M_{k0}}{M_0} \ln \frac{M_{k0}}{M_0} + \ln M_{kt}) + B_{pA} \sum n_{kt} \frac{M_{k0}}{M_0} A_k]$$
$$w_t = \frac{1}{D(p_t)} [\alpha_p + B \ln p_t - Bi (\xi_t^{dd} + \ln M_{kt}) + B_{pA} \xi_t^L]$$

Next, the aggregate expenditures on the 4 bundles are allocated to the 27 commodities according to the tier structure in Table 1. This is done with a linear logarithmic function that allows the shares to change over time. For example, for the Transportation bundle, the value of expenditures (vc_{TR}), the price index (p_{TR}^{CE}) and implied quantity is:

(A35)
$$vc_{TR} = p_{TR}^{CE} c_{TR} = p_{15}^{CE} C_{15} + p_{16}^{CE} C_{16} + p_{16}^{CE} C_{17}$$
$$\ln p_{TR,t}^{CE} = \alpha_{18,t} \ln p_{18,t}^{CE} + \alpha_{19,t} \ln p_{19,t}^{CE} + \alpha_{20,t} \ln p_{20,t}^{CE} ; \quad \alpha_{18,t} + \alpha_{19,t} + \alpha_{20,t} = 1$$
$$c_{TR,t} = vc_{TR,t} / p_{TR,t}^{CE}$$

The demand for gasoline, item 15, is then:

(A36)
$$C_{15,t} = \alpha_{15,t} vc_{TR} / p_{15}^{CE}$$

The consumption items listed in Table 1 are those used in the consumption survey and must be linked to the factory gate values in the Input-Output Accounts. For example, Food & tobacco in the Consumption accounts consist of commodities from Agriculture, Food Manufacturing, Trade (Commerce) and Transportation in the IO categories. The CE superscript denotes that these are prices for the consumption expenditure items. Table 2 gives the bridge that links these two accounts in the benchmark year 2014 for urban consumption. Column *i* of the bridge $\mathbf{H}$ gives the shares to allocate consumption item *i* to the 33 IO commodities. Let be VC_t^{CE} the vector of consumption values, and the vector of consumption in IO terms is then given by:

(A37) $VC_t^{IO} = \mathbf{H} VC_t^{CE}$

The prices of the consumption commodities are linked to the prices of the IO commodities via the same share matrix:

(A38) $p_t^{CE} = \mathbf{H}' P_t^{C,IO}$

The total value of consumption of commodity *i* is then decomposed to price and quantity:

(A39) $VC_{it}^{IO} = p_{it}^{C,IO} C_{it}$

The value of national consumption in equation (A29) is the sum over all the commodities:

(A40) $$\begin{aligned} VCC_t &= \sum_i VC_{it}^{IO} \\ &= p_{FD,t} C_{FD,t} + p_{CG,t} C_{CG,t} + C_{HS,t} p_{HS,t} + p_{SV,t} C_{SV,t} \\ &= \sum_i VC_{it}^{CE} \end{aligned}$$

Table 2. Bridge to link Consumption Expenditures to Input-Output accounts for 2014

		Food, Tobacco	Dining Out	Clothes		Applian-ces	Health-care	
		1	2	3	…	11	24	…
Agri	1	0.185	0.000	0.000		0.000	0.000	
Coal	2	0.000	0.000	0.000		0.000	0.000	
crude	3	0.000	0.000	0.000		0.000	0.000	
natgas	4	0.000	0.000	0.000		0.000	0.000	
nonenergy	5	0.000	0.000	0.000		0.000	0.000	
Food	6	0.731	0.300	0.000		0.000	0.000	
textile	7	0.000	0.000	0.050		0.000	0.000	
apparel	8	0.000	0.000	0.813		0.000	0.000	
lumber	9	0.000	0.000	0.000		0.000	0.000	
paper	10	0.000	0.000	0.000		0.000	0.000	
refine	11	0.000	0.000	0.000		0.000	0.000	
chem	12	0.002	0.000	0.000		0.011	0.196	
Build	13	0.000	0.000	0.000		0.000	0.000	
pmetal	14	0.000	0.000	0.000		0.001	0.000	
metal	15	0.000	0.000	0.000		0.000	0.000	
machin	16	0.000	0.000	0.000		0.026	0.000	
tequip	17	0.000	0.000	0.000		0.030	0.000	
emachin	18	0.000	0.000	0.000		0.641	0.038	
electro	19	0.000	0.000	0.000		0.162	0.000	
water	20	0.000	0.000	0.000		0.000	0.000	
other	21	0.000	0.000	0.001		0.010	0.004	
Elect	22	0.000	0.000	0.000		0.000	0.000	
gasprod	23	0.000	0.000	0.000		0.000	0.000	
constr	24	0.000	0.000	0.000		0.000	0.000	
transp	25	0.014	0.000	0.031		0.023	0.005	
commun	26	0.000	0.000	0.000		0.000	0.000	
commerc	27	0.067	0.000	0.101		0.970	0.123	
hotel	28	0.000	0.700	0.000		0.000	0.000	
finance	29	0.000	0.000	0.000		0.000	0.089	
realest	30	0.000	0.000	0.000		0.000	0.000	
business	31	0.000	0.000	0.000		0.000	0.000	
service	32	0.000	0.000	0.005		0.000	0.545	
admin	33	0.000	0.000	0.000		0.000	0.000	
Sum of shares		1.000	1.000	1.000		1.000	1.000	

A.1.3. Government and Taxes

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

$$\text{(A41)}\quad Rev = tax(k) + t^L PL.LS + t^V \sum_j (P_j^{KD} KD_j + PL_j LD_j + PT_j TD_j)$$
$$+ \sum_j t_j^t PI_j QI_j + \sum_j t_j^{res} PI_j QI_j + R\_CON + \sum_i t_i^r ePM_i^* M_i$$
$$+ R\_EXT + R^{ETS} + FEE + FEE^{ent}$$

where *tax(k)* is the tax on capital (eq. A67a) and X_i and M_i are the exports and imports of good i.

If there is a tax that is payable only by households on consumption this is represented by:

$$\text{(A42)}\quad P_{it}^{C,IO} = (1 + t_{it}^c) PS_{it}$$

$$\text{(A43)}\quad R\_CON_t = \sum_i t_{it}^c PS_{it} C_{it}$$

where the consumer price $P_{it}^{C,IO}$ is used in eq. (A39) above.

The revenue from the externality, or green, taxs on output and imports, is the sum of ad valorem taxes (t_{jt}^x, t_{jt}^{rx}) and unit taxes ($t_{jt}^{xu}, t_{jt}^{rxu}$):

$$\text{(A44)}\quad R\_EXT_t = \sum_j t_{jt}^x PI_{jt} QI_{jt} + \sum_j t_{jt}^{xu} QI_{jt} + \sum_i t_{it}^{rx} PM_{it} M_{it} + \sum_i t_{it}^{rxu} M_{it}$$

In one application of the model described in Ho and Nielsen (2007, Chapter 10), the externality tax rate is set proportional to the marginal air pollution damages from output *j*:

$$\text{(A45)}\quad t_{jt}^x = \lambda MD_{jt-1}^O$$

When we consider an upstream tax on fossil fuels based on the carbon content, the externality tax per (constant yuan) unit of fuel *j* is:

$$\text{(A46)}\quad t_j^{xu} = tx_{CO2}^u \; XP_j^{CO2} \qquad ,$$

where XP_j^{CO2} is the CO2 content per unit of fuel of type *j* (e.g. tons of CO2 per billion ¥2014) and the carbon tax is tx_{CO2}^u ¥/ton CO2. The emission coefficient is described in detail in equation (A8.21). There may also be green tariffs on imports and these are denoted by t_{it}^{rx} and t_{it}^{rxu}.

Carbon taxes may also be placed on non-combustion (process) emissions, such as those from cement manufacturing or other GHG emissions from chemical manufacturing and mining. This process tax per unit of output of industry j is given by the emission coefficient multiplied by the carbon tax per ton of CO2:

(A46b) $$t_j^{xpu} = tx_{CO2}^u \; XP_j^{proCO2}$$

In the particular case of cement processes, we account for the fact that cement is just a part of the non-metallic mineral (NMM) products sector and the unit tax rate for process emissions for NMM involves the value share of cement in total NMM (α_{NMM}^{cement}):

(A46c) $$t_j^{xpu} = tx_{CO2}^u \; XP_{cement}^{proCO2} \alpha_{NMM}^{cement}$$

We allow a downstream carbon price that is payable by specific buyers of fossil fuels, e.g. those covered by an Emission Trading System, and exempted for all others. The price of input *i* is denoted by PS_i; this is the aggregate of domestic and imported commodities as explained in equation (A73) below. The downstream price paid by the purchaser *j* of input *i* that includes the carbon price on the combusted portion of input *i* is:

(A47) $$PB_{ijt} = PS_{it} + t_{ijt}^{x,CO2} \; \rho_{ij}^{cmb} \qquad i \in I_{COM}^{CO2} = \{\text{coal, oil mining, gas mining, } \ldots\}$$

$$t_{ijt}^{x,CO2} = \begin{cases} t_{ijt}^{x,CO2} & j \in \text{covered industry} \\ 0 & otherwise \end{cases}$$

$$t_{ijt}^{x,CO2} = tx_{CO2,t}^u XC_{ijt}^{CO2}$$

(A47b) $$PB_{elec,jt} = PS_{elec,t} + tx_{elec,jt}^{x,CO2} \qquad i = elect, \quad j \in \text{covered industry}$$

$$tx_{elec,jt}^{x,CO2} = tx_{CO2,t}^u XP_{elec}^{CO2}$$

The set I_{COM}^{CO2} are the commodities liable for a carbon price or permit; this would usually include the coal, oil and gas inputs. The emission intensity coefficient XC_{ijt}^{CO2} is given in A8.25 in section 8. Eq. A47b is for the case that electricity input is liable for a CO2 price on the embodied carbon, otherwise the input price is simply $PS_{elec,t}$ (XP_{elec}^{CO2} is explained in eq. A.8.21b). The combustion ratios ρ_{ij}^{cmb} are in eq. (A8.12); fuels that are converted to other products such as plastics or tar, are not liable for a CO2 price.

A downstream carbon tax may also be put on household (final demand); this is represented by this addition to equation A42 above:

(A47c) $P_{it}^{C,IO} = (1+t_{it}^{c})PS_{it} + t_{i,hh,t}^{x,CO2}; \qquad t_{i,hh,t}^{x,CO2} = tx_{CO2}^{u} XP_i^{CO2}$

The revenue from the emission permit price in the ETS is:

(A48) $R_t^{ETS} = \sum_{i\in I_{COM}^{CO2}} \sum_{j\in Covered} t_{ij}^{xCO2} \rho_{ij}^{cmb} A_{ij} + \sum_{j\in Covered} t_{elec,j}^{xCO2} A_{elec,j} + t_j^{xpu} QI_j$

where A_{ij} is input *i* measured in constant yuan given by (A14).

The price of output j is given by eq. (19). Collecting all the taxes together to give the full effective tax rate on j's output, we have:

(A48b) $PI_j^t = (1+tt_j^{full})PI_j$

$$tt_j^{full} = t_j^t + t_j^{res} + t_j^x + (t_j^{xu} + t_j^{xpu} - s_{jt}^{CO2}) / PI_j$$

The last term of the revenue equation represent nontax payments to the government which are set as a fixed share of household income:

(A49) $FEE_t = \gamma^{NHH} Y_t^p$

Total government expenditure is the sum of commodity purchases (*VGG*) and other payments:

(A50) $$\begin{aligned} Expend &= VGG + G\_INV + \sum s_i^e PI_i X_i + G\_I + G\_IR \\ &+ G\_ETS + G\_transfer \end{aligned}$$

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

(A51) $PS_i G_i = \alpha_i^G VGG$.

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

(A52) $GG = \dfrac{VGG}{PGG}$.

G_I and G_IR are interest payments to domestic households and rest-of-the-world, respectively. Transfers are set equal to a fixed rate of the population multiplied by the wage rate:

(A53) $G\_transfer = \gamma^{tr} PL_t POP_t$

In an Emission Trading System the government may auction some emission permits and issue some free permits. We simplify the accounting by first computing the total value of permits and considering that as the gross revenue, R_CO2_t. Let the free allocation of permits to industry *j* be AL_{jt}^{CO2}. The value of the freely allocated permits may be considered an expense of the government under the simplified accounting of gross revenue:

(A54) $G\_ETS_t = \sum_j tx_{CO2}^u \ AL_{jt}^{CO2}$

We also allow for the use of some of the auction revenues to subsidize the sectors under the CO2 cap. In this case the total subsidy is given by:

(A55) $G_t^{ETS\_SUB} = \sum_j s_{jt}^{CO2} QI_{jt}$

The subsidy rate, s_{jt}^{CO2}, may differ by industry, e.g. higher rates for the more carbon intensive sectors. We implement a simple system of subsidy rates based on the carbon:output ratio in the base year:

(A56) $s_{jt}^{CO2} = s_t^{CCOV} \theta_{j0}^{CO2}$; $\qquad \theta_{j0}^{CO2} = EM_{j,CO2,2014} / QI_{j2014}^t$

The allocation of free permits may be determined by complex formulas such as "most efficient producer intensity," or "historical emission intensity." If it does not depend on any current decision, for example, as a function of historical emissions, then we treat it as an exogenous transfer to the covered industry:

(A57) $AL_{jt}^{CO2} = \overline{AL}_{jt}^{CO2}$

If the entire free allocation depends on current output by multiplying with a predetermined coefficient, then it reduces to an output subsidy system shown in eq. (A55). That is, the subsidy rate, s^{CCOV}, is chosen to equal the free-allocation budget:

(A58) $G_t^{ETS\_SUB} = \sum_j s_t^{CCOV} \theta_{j0}^{CO2} QI_{jt} \ = G\_ETS_t$

That is, the *G_ETS* item in the expenditure equation (A50) is either given by (A54) or (A58).

If a portion of the permits are auctioned and a portion freely allocated, then the auction revenue may be used to cut existing taxes to ensure that the policy is revenue-neutral. This is discussed in more detail in the policy examples in section A9 below. The value of the free, non-auctioned, permits (equal to output subsidies in the case of A58), is equal to the total permit purchases (R^{ETS}) less the auction share (α_t^{CO2auc}):

(A58b) $$G\_ETS_t = (1-\alpha_t^{CO2auc})R_t^{ETS}$$

If there is an output subsidy, then s_i^{CO2} would be positive in the output price equation (A19) of covered sector *j*:

(A59) $$PI_j^t \;=\; (1+t_j^t+t_j^{res}+t_j^x-s_{jt}^{CO2})PI_j \;+\; t_j^{xu}+t_j^{xpu}$$

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

(A60) $$\Delta G_t \;=\; Expend_t \;-\; Rev_t \quad ,$$

(A61) $$B_t \;+\; B_t^{G*} \;=\; B_{t-1} \;+\; B_{t-1}^{G*} \;+\; \Delta G_t \quad .$$

The deficit and interest payments are set exogenously and equation A40 is satisfied by making the level of total nominal government expenditure on goods, VGG, endogenous in the base case. In simulating policy cases we would often set the real government expenditures in the policy case equal to those in the base case (GG_t^{Base}). In this counterfactual we would use some endogenous tax variable to satisfy:

(A62) $$GG_t \;=\; GG_t^{Base}$$

A.1.4. Capital, Investment, and the Financial System

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

(A63) $K_{jt} = \bar{K}_{jt} + \tilde{K}_{jt}$.

The plan portion evolves with plan investment and depreciation:

(A64) $\bar{K}_{jt} = (1-\delta)\bar{K}_{jt-1} + \psi_t^I \bar{I}_{jt}$, t = 1, 2, …, T .

The rate of depreciation is δ, and ψ_t^I is an aggregation that converts the investment units to capital stock units[2]. In this formulation, $\bar{K}_{j0}$ is the capital stock in sector *j* at the beginning of the simulation. This portion is assumed to be immobile across sectors. Over time, with depreciation and limited government investment, it will decline in importance. Each sector may also rent capital from the total stock of market capital, $\tilde{K}_t$:

(A65) $\tilde{K}_t = \sum_j \tilde{K}_{jt}$, where $\tilde{K}_{ji} > 0$.

The allocation of market capital to individual sectors, $\tilde{K}_{jt}$, is based on sectoral rates of return. As in equation A2, the rental price of market capital by sector is $\tilde{P}_j^{KD}$. The supply of $\tilde{K}_{jt}$, subject to equation A25, is written as a translog function of all of the market capital rental prices, $\tilde{K}_{jt} = K_j(\tilde{P}_1^{KD}, \ldots, \tilde{P}_n^{KD})$:

(A66) $\dfrac{\tilde{K}_{jt}}{\tilde{K}_t} = \alpha_j^{KS} + \sum_k B_{jk}^K \log \tilde{P}_{kt}^{KD}$

In three sectors, agriculture, crude petroleum and gas mining, "land" is a factor of production. We have assumed that agricultural land and oil fields are supplied inelastically, abstracting from the complex property rights issues regarding land in China. After taxes, income derived from plan capital, market capital, and land is either kept as retained earnings by the enterprises, distributed as dividends[3], or paid to foreign owners:

[2] Both K and I are aggregates of many asset types, ranging from computer equipment to structures. The composition of total investment and total capital stock are different and an aggregation coefficient is needed to reconcile the historical series.

[3] In China, a substantial part of the "dividends" are actually income due to agricultural land.

(A67) $\sum_j profits_j \; + \; \sum_j \tilde{P}_j^{KD}\tilde{K}_j \; + \; \sum_j PT_j T_j \;\; = vat(k) + \; tax(k) \; + \; RE \; + \; DIV \; + \; r(B^*)$,

The tax on enterprise income is levied on the cash flow, which is capital and land value added less the value added tax (implicit rental value of agriculture land is not taxed):

(A67a) $$tax(k) = \sum_j tk_j (1-t^V) P_j^{KD} KD_j + \sum_{j=2,3} tk_j (1-t^V) PT_j T_j$$

The dividend paid to households is given by a dividend payout rate multiplied by the cash flow, plus the entire land rental from agriculture:

(A67b) $$DIV = DIV^{ent} + DIV^{agri}$$

$$DIV^{ent} = \gamma^{div} [\sum_j (1-t^V) P_j^{KD} KD_j + \sum_{j=2,3} (1-t^V) PT_j T_j - r(B^*) - tax(k) - FEE^{ent}]$$

$$DIV^{agri} = (1-t^V) PT_{agri} T_{agri}$$

The retained earnings are profits less VAT, capital taxes, nontax fees and distributions:

(A67c) $$RE = \sum_j (1-t^V) P_j^{KD} KD_j + \sum_{j=2,3} (1-t^V) PT_j T_j - tax(k) - DIV^{ent} - NFY - FEE^{ent}$$

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

(A68) $PS_{it} I_{it} \; = \; \alpha_{it}^I VII_t$.

A portion of sectoral investment, $\bar{I}_t$, is allocated directly by the government, while the remainder, $\tilde{I}_t$, is allocated through other channels.[4] The total, I_t, can be written as:

(A69) $I_t \;\; = \;\; \tilde{I}_t \; + \; \bar{I}_t \;\; = \;\; I_{1t}^{\alpha_1^I} \, I_{2t}^{\alpha_1^I} \ldots I_{nt}^{\alpha_n^I}$.

As in equation A43 for the plan capital stock, the market capital stock, $\tilde{K}_{jt}$, evolves with new market investment:

(A70) $\tilde{K}_{jt} \;\; = \;\; (1-\delta)\tilde{K}_{jt-1} \; + \psi_t^I \tilde{I}_{jt}$.

Non-reproducible assets

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

In addition to the capital stock, the households own the non-reproducible asset – land. The supply of land (or mining resources) is simply assumed fixed for each type (agriculture, coal mining, oil mining):

(A71) $T_{jt} \quad = \quad T_{j0}$

A.1.5. The Foreign Sector

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

(A72) $$DS_i \quad = \quad A_0 \left[\alpha^d DC_i^\rho \;+\; \alpha^m M_i^\rho \right]^{\frac{1}{\rho}} \qquad ,$$

where DC is the quantity of domestically produced goods that are sold domestically. The elasticity is $\sigma = 1/(1-\rho)$. The cost dual corresponding to the above primal function is:

(A73) $$PS_i \quad = \quad \frac{1}{A_0} \left[\alpha^{d\sigma} PD_i^{1-\sigma} \;+\; \alpha^{m\sigma} M_i^{1-\sigma} \right]^{\frac{1}{1-\sigma}}$$

and the value of total domestic supply is:

(A74) $$VQS_i = PS_i DS_i \;=\; PD_i\, DC_i + PM_i M_i$$

The purchaser's price for domestic goods, PD_i , is related to the commodity supply price PC_i and is discussed in the export section below. PS_i is the price of the basket of commodity *i* to domestic purchasers. The price of imports to buyers is the foreign price plus tariffs (less export subsidies), multiplied by a world relative price, *e*:

(A75) $$PM_i \quad = \quad e(1 + t_i^r + t_i^{rx}) PM_i^* + t_i^{rxu} \qquad .$$

From (A73) we may derive the demand for imports as:

(A76) $$\frac{PM_i M_i}{PS_i DS_i} \;=\; \frac{\alpha^{m1/1-\rho} M_i^{\rho/\rho-1}}{\alpha^{d1/1-\rho} DC_i^{\rho/\rho-1} + \alpha^{m1/1-\rho} M_i^{\rho/\rho-1}}$$
$$= \frac{\alpha^{m\sigma} PM_i^{1-\sigma}}{\alpha^{d\sigma} PD_i^{1-\sigma} + \alpha^{m\sigma} PM_i^{1-\sigma}}$$

Domestically produced commodities (QC) are allocated to the domestic market and exports according to a constant elasticity of transformation (CET) function:

$$\text{(A77)}\quad QC_{it} = \kappa_{it}^{x}\left[\alpha_{it}^{x} X_{it}^{\frac{\sigma_i^e - 1}{\sigma_i^e}} + \left(1 - \alpha_{it}^{x}\right) DC_{it}^{\frac{\sigma_i^e - 1}{\sigma_i^e}}\right]^{\frac{\sigma_i^e}{\sigma_i^e - 1}}$$

The ratio of exports to domestically sold goods depends on the domestic price (PD) relative to world prices adjusted for export subsidies (s_{it}^{e}):

$$\text{(A78)}\quad X_{it} = DC_{it}\left[\frac{1 - \alpha_{it}^{x}}{\alpha_{it}^{x}}\frac{PD_{it}}{PX_{it}}\right]^{\sigma_{t,r}^{e}} ; \qquad PX_{it} = e_t(1 + s_{it}^{e})PE_{it}^{*}$$

The value identity is:

$$\text{(A79)}\quad PC_{it}QC_{it} = PD_{it}DC_{it} + PX_{it}X_{it}$$

The weights and constant terms are set using base year values:

$$\text{(A80)}\quad \alpha_{it}^{x} = \frac{PD_{i0}X_{i0}^{-1/\sigma_{t,r}^{e}}}{PD_{i0}X_{i0}^{-1/\sigma_{t,r}^{e}} + PX_{i0}DC_{i0}^{-1/\sigma_{t,r}^{e}}} ; \kappa_{i}^{x} = QC_{i0} / \left[\alpha_{i0}^{e} X_{i0}^{\frac{\sigma_{t,r}^{e}-1}{\sigma_{t,r}^{e}}} + \left(1-\alpha_{i0}^{e}\right) DC_{i0}^{\frac{\sigma_{t,r}^{e}-1}{\sigma_{t,r}^{e}}}\right]^{\frac{\sigma_{t,r}^{e}}{\sigma_{t,r}^{e}-1}}$$

The share parameters α_{it}^{x} are projected exogenously to take into account the rising role of exports during 1980-2014 and a falling role in the future. The price *PC* is given in equation (A21) above, and is also an implicit dual function of (A77), *PC*=f(*PX*,*PD*).

The current account balance is equal to exports minus imports (valued at world prices before tariffs), less net factor payments, plus transfers:

$$\text{(A81)}\quad \begin{aligned} CA &= \sum_i \frac{PX_i X_i}{(1 + s_i^e)} - \sum_i ePM_i^{*} M_i - r(B^{*}) - G\_IR + R\_transfer \\ &= VX - VM - r(B^{*}) - G\_IR + R\_transfer \end{aligned} ,$$

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

$$\text{(A82)}\quad B_t^{*} + B_t^{G*} = B_{t-1}^{*} + B_{t-1}^{G*} - CA_t \quad .$$

A.1.6. Markets

The economy is in equilibrium in period *t* when the market prices clear the markets for the 33 commodities and the three factors. The supply of domestically produced commodity *i* must satisfy the total of intermediate and final demands:

(A83) $$DS_i = \sum_j A_{ij} + C_i + I_i + G_i \quad , \quad i = 1, 2, \ldots, 33.$$

For the labor market, we assume that labor is perfectly mobile across sectors so there is one average market wage which balances supply and demand. As is standard in models of this type, we reconcile this wage with the observed spread of sectoral wages using wage distribution coefficients, ψ_{jt}^L. Each industry pays $PL_{jt} = \psi_{jt}^L PL_t /(1-t_j^V)$ for a unit of labor. The labor market equilibrium is then given as:

(A84) $$\sum_j \psi_{jt}^L LD_{jt} = LS_t \quad .$$

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

(A85) $$KD_{jt} = \psi_{jt}^K K_{jt} \quad ,$$

where ψ_{jt}^K converts the units of capital stock into the units used in the production function.

The rental price PT_j adjusts to clear the market for “land”:

(A86) $TD_j = T_j \quad , \qquad j$ = “agriculture”, “crude petroleum”, "gas mining".

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

(A87) $$S^p + RE + G\_INV = VII + \Delta G + CA \quad .$$

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

The model is a constant returns-to-scale model and is homogenous in prices, that is, doubling all prices leaves the economy unchanged. We are free to choose a price normalization.

A.1.7 Welfare and Other accounting identities

The household welfare function (A30) is chosen to allow aggregation over different households. The aggregation issues are discussed in Jorgenson et al. (2013, Chapter 3); equation (A34) gives the aggregate demand function for the four consumption bundles. Jorgenson et al. expresses social welfare as a function that takes into account the different compositions of households (different size and number of children), using the concept of household equivalents. The welfare (*W*) function depends on the average level of consumption as well as inequality of consumption (efficiency and equity). Here we compute only the average levels to give the efficiency measure which is given by:

(A7.1) $$W = \ln \bar{V} = \frac{\sum_k m_0(p, A_k) \ln V_k}{\sum_k m_0(p, A_k)}$$

V_k is the household utility in (A30), and $m_0(p, A_k)$ is the household equivalent to the reference household which is aged 18-34, male, elementary school, two members and in the East. The equivalence scale is explained in Jorgenson and Slesnick (1987) and is given by:

(A7.2) $$\ln m_0(p, A_k) = \frac{1}{D(p)}[\ln p' B_{pA} A_k]$$

The money measure of welfare is given by a social expenditure function (Jorgenson and Slesnick 1987, eq. 5.15):

(A7.3) $$\ln M(p, W) = \frac{1}{D(p)}[\ln p' \alpha_p + \frac{1}{2} \ln p' B \ln p - W] + \ln \sum_k m_0(p, A_k)$$

The money measure of the change in welfare due to a policy (from W^0 to W^1) is a function of the policy case measured at base case prices (p^0):

(A7.4) $$\Delta M = M(p^0, W^1) - M(p^0, W^0)$$

Gross domestic product in nominal terms is the sum of consumption, investment, government spending, plus net exports:

(A7.5) $$VGDP = VCC + VII + VGG \ + VX - VM$$

To construct real, constant yuan, GDP we need to first define real consumption, investment, etc. These are expressed as the divisia aggregate of the 33 commodities that make up each component, for example, real personal consumption expenditures is:

(A7.6) $CC^{div} = divisia(C_i ; PS_i^C)$

$$\Delta \ln \frac{CC_t^{div}}{CC_{t-1}^{div}} = \sum_i \tfrac{1}{2}(v_{it}^c + v_{i,t-1}^c)\Delta \ln \frac{C_{it}}{C_{i,t-1}} ; \qquad v_{it}^c = \frac{PS_{it}C_{it}}{VCC_t}$$

Real GDP is then a divisia index of these components:

(A7.7) $rGDP = divisia(CC^{div}, II^{div}, GG^{div}, X^{div}; PCC,...) - M^{div}$

A.1.8 Energy, emissions and environmental accounting

To account for atmospheric environmental damages we consider a range of criteria pollutants: particulate matter (PM_{25} and PM_{10}), sulphur dioxide, nitrogen oxides, VOCs, and ammonia. We also account for greenhouse gas emissions, in particular carbon dioxide. The PM concentration is due to primary PM emissions as well as secondary particles such as sulfates and nitrates which are formed from sulfur dioxide and NOx respectively. The emissions inventory is described in *Clearer Skies*, Chapters 4-6. To illustrate the calculations, we describe here a simplified account of energy flows and primary PM, SO2 and NOx emissions.

We begin by describing the energy variables. Very often a simple indicator of total primary energy production and consumption is produced by summing the energy equivalents of the fossil fuels and primary electricity and heat. This may not be a very useful indicator given that a joule of energy from burning coal is very different in the ease of use from a joule from gasoline or a joule of electricity; a difference that is reflected in the prices per joule. Nevertheless, for comparison with well-known series we compute the standard coal equivalent (sce) of these primary sources of energy.

First, recall that we distinguish between industry output (*QI*) and commodity output (*QC*). QC_{ft} is the constant yuan quantity of commodity produced (billions of 2014 yuan). QP^f, the total quantity of coal, crude, or gas *produced* (whether combusted or not) in year *t* is given by the commodity output (*QC*) multiplied by the fuel conversion coefficient, ξ_{mean}^f:

(A8.1) $QP_t^f = \xi_{mean}^f QC_{f,t}$ f=coal, crude oil, gas mining

where ξ_{mean}^f is the quantity of the commodity output (in million tons, million m^3, or billion kWh) per billion yuan of commodity output. For example, the quantity of raw coal produced in million tons is given by $QP_t^{rawcoal} = \xi_{mean}^{coal} QC_{coal,t}$. Since electricity is only a part of the "Electricity, Steam & Hot water" sector, the quantity of electricity produced (in billion kWh) is:

$$QP_t^{elect} = \xi_{mean}^{elect} \alpha_{elect}^{el\_only} QC_{elect,t}$$

where a^{el_only} is the electricity share of the "Electricity, Steam, & Hot water" sector's commodity output.

Jorgenson et al. 2018 discusses two distinct approaches to accounting for energy use and emissions – a top down method and a bottom-up method – and we use both here. The first way simply uses the total output of fuels (production-based account); the second way sums over the industry consumption of energy that is calibrated to the official estimates in the base year (consumption-based account). First, E^{PROD}, the total sce of energy produced domestically, is:

(A8.2) $E_t^{PROD} = e_{coal} QP_t^{rawcoal} + e_{oil} QP_t^{oil} + e_{gas} QP_t^{gas} + e_{elect} QP_t^{PRIelec}$

where e_f is the energy content of a unit of fuel f (e.g. tons of sce per ton of oil) and the PRI superscript denotes primary electricity from renewables and nuclear. (In this calculation we ignore the tiny amount of heat from natural sources.) We set $\alpha^{PRIelec}$, the share of electricity produced from primary sources, exogenously by considering the projected generation of renewables and nuclear power. Then $QP^{PRIelec}$, the quantity of primary electricity produced from renewables and nuclear, is:

(A8.3) $QP_t^{PRIelec} = \alpha_t^{PRIelec} QP_t^{elec}$

E^{EXP}, the total sce of energy exported, on net, is:

(A8.4) $E_t^{EXP} = e_{coal} \xi_{mean}^{coal} (X_{coal,t} - M_{coal,t}) + e_{oil} \xi_{mean}^{oil} (X_{crude,t} - M_{crude,t} + X_{refine,t} - M_{refine,t})$

$$+ e_{gas} \xi_{mean}^{gas} (X_{natgas,t} - M_{natgas,t})$$

where X_f is the value of exports of fuel f (in billion Yuan) and M_f is the value of imports of fuel f (in billion Yuan). Exports of electricity are not counted in this measure since it is a secondary energy, the pollution due to the generation of electricity for exports is located in the country and they are not exported.

E^{CONS}, the total energy consumed in China (in tons sce) is then given by production less net exports, less changes in inventory (E_t^{INV}):

(A8.5) $E_t^{CONS} = E_t^{PROD} - E_t^{EXP} - E_t^{INV}$

$$
\begin{aligned}
E_t^{CONS} &= e_{coal}\xi_{mean}^{coal}(QC_{coal,t} - X_{coal,t} + M_{coal,t}) \\
&+ e_{oil}\xi_{mean}^{oil}(QC_{\mathrm{crude},t} - X_{crude,t} + M_{crude,t} - X_{refine,t} + M_{refine,t}) \\
&+ e_{gas}\xi_{mean}^{gas}(QC_{natgas,t} - X_{natgas,t} + M_{natgas,t}) \\
&+ e_{elect}QP_t^{PRIelec} - E_t^{INV}
\end{aligned}
$$

(A8.6)
$$
\begin{aligned}
E_t^{CONS} &= e_{coal}CF_t^{coal} + e_{oil}CF_t^{oil} + e_{gas}CF_t^{gas} \\
&+ e_{elect}QP_t^{PRIelec} - E_t^{INV}
\end{aligned}
$$

(A8.7) $$CF_t^{coal} = \xi_{mean}^{coal}(QC_{coal,t} - X_{coal,t} + M_{coal,t}),\ \text{etc.}$$

The second expression in (A8.5) substitute in (A8.2) and (A.8.4) to show that it is the constant yuan output less net exports, multiplied by the fuel conversion coefficient, and multiplied by the energy content coefficient. In (A8.6), the variables $CF_t^{coal}, CF_t^{oil}, CF_t^{gas}$ denote the quantity of fuel consumed in million tons or million m^3. Here, CF^f is calculated as the sum of commodity output (*QC*) and imports (*M)* less exports (*X*), multiplied by the fuel conversion coefficient (ξ_{mean}^{f}) to convert the constant yuan of fuel consumed into the quantity of fuel consumed (in million tons or million m^3).

Second, in consumption-based accounting, we also calculate national energy consumption by adding over each industry, using industry specific information about the consumption of coal, coke, liquid fuels, etc. We first define consumption coefficients (ξ_j^f) by taking the data on fuel actually used (in million tons, million m^3, or billion kWh) from the China Statistical Year book (CSY 2012, Table 7-9 "Consumption of Energy by Sector") and dividing by the value of energy purchases given in the Input-Output table.

To disambiguate, the fuel conversion coefficient (ξ_{mean}^{f}), presented in equation (A8.1), is computed using the production data at the aggregate level: the *total* quantity of the fuel *f* produced divided by the *total* value of commodity output *f*. In contrast, the consumption coefficient (ξ_j^f), presented here, is computed using the consumption data at the industry level: industry *j*'s consumption of fuel *f* (in million tons, million m^3, or billion kWh) divided by the value of industry *j*'s purchases of fuel *f* (in billion yuan).

Secondary fuels are produced by the Petroleum Refining & Coal Products sector which we group as coke, combustible refined products (refined liquids & petcoke), and other petroleum products. The "other petroleum products," such as bitumen and lubricants, are assumed to be not combusted (i.e. not contributing to CO2 emissions). Each industry *j* purchase a different share of coke (coal products) from this sector and we write the value of coke input as a share of the value of Refining & Coal Products in the Use matrix: $\alpha_{ref\_co,j}^{coalpr} U_{refine,j}$, where $a^{f}_{s,j}$ is the share of fuel *f* in sector *s* that industry *j* purchases, and $U_{f,j}$ is the value (in billion Yuan) of inputs of fuel *f* for industry *j* from the Use matrix.

The value of Combustible Refined Products and Other Petroleum Products consumed are then:

$$\alpha_{refine}^{cmb}(1-\alpha_{ref\_co,j}^{coalpr})\,\mathrm{U}_{refine,j}\,; \qquad (1-\alpha_{refine}^{cmb})(1-\alpha_{ref\_co,j}^{coalpr})\,\mathrm{U}_{refine,j}$$

That is, the value of refined liquids is the product of: 1) the share of liquids in total refined petroleum products; 2) the share of *non*-coal products in the Refining & Coal Products sector that industry *j* purchases; and 3) the value of Refining & Coal Products purchased by industry *j*. Similarly, the value of Other Petroleum Products input (on the right) can be interpreted as the product of: 1) the share of *non*-liquids in total refined petroleum products; 2) the share of *non*-coal products in the Refining & Coal Products sector that industry *j* purchases; and 3) the value of Refining & Coal Products purchased by industry *j*.

The energy consumption coefficients for coke and combustible refined oil are thus:

(A8.8) $$\xi_{j,baseyr}^{coke} = \frac{FT_{coke,j,baseyr}^{CSY}}{\alpha_{ref\_co,j}^{coalpr} U_{refine,j,baseyr}}\,; \qquad \xi_{j,baseyr}^{refcmb} = \frac{FT_{refcmb,j,baseyr}^{CSY}}{\alpha_{refine}^{cmb}(1-\alpha_{ref\_co,j}^{coalpr}) U_{refine,j,baseyr}}$$

where $FT_{coke,j,baseyr}^{CSY}$ is the quantity of coke consumed by *j* in million tons in the base year 2014; FT_{refcmb}^{CSY} is the sum of the quantity of gasoline, kerosene, diesel, fuel oil and petcoke consumed (given in CSY 2015); and $FT_{otherpetroleum}^{CSY}$ is the sum of the quantity of lubricant, bitumen, naphta, etc. consumed (given in the LBL's China Energy Databook).

(A8.9) $$\alpha_{refine,j}^{refcmb} = FT_{refcmb,j}^{CSY} / (FT_{refcmb,j}^{CSY} + FT_{\text{otherpetroleum},j})$$

is the quantity share of liquids consumed in consumption of total refined petroleum products for industry *j*.

Our model distinguishes between the Gas Mining sector and the Gas Utilities (or Gas Products) sector; most industries purchase only from Gas Products, while a few purchase from Gas Mining for transformation and combustion – Chemicals, Electricity and Gas Products. For all industries *j* other than Gas Products the consumption coefficient is the *quantity* of natural gas purchased by industry *j* divided by the sum of the *values* of natural gas and gas products purchased by industry *j* in the base year:

$$\text{(A8.10)} \qquad \xi_{j,baseyr}^{natgas} = \xi_{j,baseyr}^{gasprod} = \frac{FT_{\text{natgas},j,baseyr}^{CSY}}{U_{\text{natgas},j,baseyr} + U_{\text{gasprod},j,baseyr}} \qquad j \neq \text{Gas Products}$$

In contrast, the energy consumption coefficient for the Gas Products industry is divided by only the value in the Gas Products cell, excluding the Gas Mining cell:

$$\text{(A8.11)} \qquad \xi_{j=gasprod,baseyr}^{gasprod} = \frac{FT_{\text{natgas},j,baseyr}^{CSY}}{U_{\text{gasprod},j,baseyr}}$$

We now move on from calculating energy consumption to calculating energy combustion. The above consumption coefficients refer to the *purchases* of the different fuels. Some of these oil and gas inputs are not combusted, but rather, converted to other products such as fertilizer or bitumen. In the Refining sector, part of the crude input is combusted but most are converted to liquid fuels or other petroleum products; the combusted portion is represented by the “refining loss” coefficient, $\rho_j^{ref\_loss}$, where $(1-\rho_j^{ref\_loss})$ is the fraction of un-combusted crude input. (For industries other than j=Refining, $\rho_j^{ref\_loss}$ is simply 1, reflecting that 100% of the crude input is combusted.)

In the Gas Products (Utilities) industry, gas is purchased from the Natural Gas Mining sector and sold to consumers; that is, there is assumed to be no combustion in Gas Products. In the Chemicals sector, raw gas is purchased from the Gas Mining sector and part of it is converted to plastics and other products. The combusted portion is represented by $\rho_{j=Chemical}^{gas\_loss}$. (For industries other than j=Chemical, $\rho_{j=Chemical}^{gas\_loss}$ is simply 1, reflecting that 100% of the raw gas is combusted). Thus, these loss adjustment coefficients can be thought of as the share of fuel *f* that *is* combusted for industry *j*.

To disambiguate in advance: FT_{fj}^{CSY} (used in the previous section) refers to the quantity of fuel *f purchased*, while FT_j^f (used below) refers to the quantity of fuel *f combusted*.

The quantity of fuel **combusted** (*FT*) is given by the constant yuan of fuel (A_{ij}) multiplied by the consumption coefficients (ξ_j^f , that converts the value of fuel *f* to physical quantities (tons of coal, tons of oil, m^3 of gas, kWh of electricity)), and multiplied by these loss adjustments ($\rho_j^{f\_loss}$). The following equations describe the quantity of fuel combusted for coal, oil, other petroleum products (*refncmb*), and gas in terms of fuels at a finer classification:

(A8.12) $$FT_{jt}^{coal} = Q_{jt}^{rawcoal} + Q_{jt}^{coke} = \xi_j^{coal} \rho_j^{coke\_loss} A_{coal,j,t} + \xi^{coalpr} \alpha_j^{coalpr} A_{refining,jt}$$

$$= \xi_j^{coal} \rho_j^{coke\_loss} U_{coal,j} / PS_{coal} + \xi_j^{coalpr} \alpha_j^{coalpr} U_{refine,j} / PS_{refine}$$

$$FT_{jt}^{oil} = Q_{jt}^{crude} + Q_{jt}^{refinedoil} = \xi_j^{oil} \rho_j^{ref\_loss} A_{oil,jt} + \xi_j^{refcmb} \alpha_{refine}^{cmb} (1 - \alpha_{ref\_co,j}^{coalpr}) A_{refining,jt}$$

$$= \xi_j^{crude} \rho_j^{ref\_loss} U_{crude,j} / PS_{crude} + \xi_j^{refcmb} \alpha_{refine}^{cmb} (1 - \alpha_{ref\_co,j}^{coalpr}) U_{refine,j} / PS_{refine}$$

$$FT_{jt}^{gas} = \xi_j^{gas} \rho_j^{gas\_loss} A_{gasmining,jt} + \xi_j^{gasprod} A_{gasprod,jt}$$

$$= \begin{cases} \xi_j^{gas} \rho_j^{gasloss} U_{natgas,j} / PS_{natgas} + \xi_j^{gasprod} U_{gasprod,j} / PS_{gasprod} & j \neq gasprod \\ \xi_j^{gasprod} U_{gasprod,j} / PS_{gasprod} & j = gasprod \end{cases}$$

where that the constant yuan quantity of energy input is given by the value in the Use matrix divided by the fuel price: $A_{ij} = U_{ijt} / PS_{it}$. Q^i is the quantity of energy input i (at the finer classification) combusted, and the quantity of fuel f combusted is the sum over the i finer types to give FT^f.

For electricity, α_{elect}^{elec} is the share of electricity in Electricity, Steam & Hot Water, and we may similarly define FT^{elect}, the quantity of electricity purchased (in billion kWh), as:

(A8.13) $$FT_{jt}^{elect} = \xi_{elect}^{elec} \alpha_t^{elec} U_{elect,j} / PS_{elect}$$

The above equations (A8.12) and (A8.13) are for the industry purchases of energy; a similar set of equations hold for household and investment use of energy:

(A8.14) $$FT_{HH,t}^{elect} = \xi_{elect}^{elec} \alpha_t^{elec} C_{elect}$$

$$FT_{HH,t}^{coal} = \xi_{HH}^{coal} C_{coal,t} + \xi^{coalpr} \alpha_{HH}^{coalpr} C_{refining,t}$$

$$FT_{HH,t}^{oil} = \xi_{HH}^{crude} C_{oil,t} + \xi_{HH}^{refcmb} \alpha_{refine}^{cmb} (1 - \alpha_{HH}^{coalpr}) C_{refining,t}$$

$$FT_{HH,t}^{gas} = \xi_{HH}^{gas} C_{gas,t} + \xi_{HH}^{gasprod} C_{gasprod,t}$$

$$FT_{INVt}^{coal} = \xi^{coal} I_{coal}; \qquad FT_{INVt}^{oil} = \xi^{oil} I_{oil}; \qquad FT_{INVt}^{gas} = \xi^{gas} I_{gas}$$

where C_{elect}, C_{coal}, $C_{refining}$, C_{oil}, C_{gas}, *and* $C_{gasprod}$ denote the constant yuan value of Consumption by households of those fuels (in billion Yuan). I_f is the value (in billion Yuan) of purchases of fuel *f* by the Investor (these are essentially business inventories in the Investment column of the input-output accounts).

The un-combusted portions in this version are the other petroleum products ("refncmb") and part of the gas use by the Chemicals industry. We denote the un-combusted fuel use by FU:

(A8.15) $$FU_{jt}^{refncmb} = \xi_j^{refother}(1-\alpha_{refine}^{cmb})(1-\alpha_{ref\_co,j}^{coalpr})U_{refine,j} / PS_{refine} \qquad \text{j=1,…33}$$

$$FU_{jt}^{gas} = \xi_j^{gas}(1-\rho_j^{gasloss})U_{natgas,j} / PS_{natgas} \qquad j\text{=Chemicals}$$

The total energy consumed by industry *j* or households is the sum of these physical units of primary fossil fuels combusted multiplied by the energy conversion coefficient (e_f, e.g. tons of SCE per ton of coal), plus the electrical energy, plus the un-combusted portions:

(A8.16) $$EIND_{jt} = e_{coal}FT_{jt}^{coal} + e_{oil}FT_{jt}^{oil} + e_{gas}FT_{jt}^{gas} + e_{elect}FT_{jt}^{elect} + e_{oil}FU_{jt}^{refncmb}$$

$$\text{j=1,…,33,HH,INV;} \quad j \neq \text{elect}$$

When we express energy consumption as above, we are counting *j*'s use of electricity as energy consumed by *j*, not as energy consumed by the Electric Utilities when it burns coal to generate electric power. For a consistent accounting of total national consumption, the net energy consumed by Electric Utilities is only the generation loss plus the Utilities own electricity consumption ($U_{elect,elect}$). The generation loss is given by the energy embodied in the fuels combusted in the power plants *less* the energy embodied in the delivered thermal electricity (total electricity minus renewables and nuclear ($QP_t^{elec} - QP_t^{PRIelec}$). The net energy consumed by Electric Utilities, $EIND_{j=elect}$, is thus:

(A8.17) $$\begin{aligned} EIND_{j=elect,t} &= e_{coal}FT_{jt}^{coal} + e_{oil}FT_{jt}^{oil} + e_{gas}FT_{jt}^{gas} \\ &-e_{elect}(QP_t^{elec} - QP_t^{PRIelec}) + e_{elect}U_{elect,j} / PS_{elect} \end{aligned} \qquad \text{j=Elect}$$

The national total energy consumption is then the sum over all industries and final demand:

(A8.18) $$E_{TOT,t}^{IND} = \sum_j EIND_{jt} + EIND_{HH,t}$$

This should be equal to E_t^{CONS}, the total computed from the production data in equation A8.7.

Emissions

The national emissions of carbon dioxide may be computed from either the production accounts or the consumption by each industry, in each case adding over the emissions from all fossil fuels *f*. The top-down accounting of emissions is given by the national quantity of fuel consumed (CF_t^f), multiplied by the energy content coefficient (e_f), and multiplied by the CO2 intensity, (c_f , tons of CO2 per sce of fuel *f*):

(A8.19) $$EM_{CO2,t}^{fos} = c_{coal}e_{coal}CF_t^{coal} + c_{oil}e_{oil}CF_t^{oil} + c_{gas}e_{gas}CF_t^{gas}$$

The quantity of fuel *f* consumed, CF_t^f, is given in equation A8.7 above. For non-combustion sources of CO2 we only consider those from cement production processes; this is expressed as an emission factor (c_{cement}) multiplied by the cement component of the output of the Building Materials industry:

(A8.20) $$EM_{CO2,t}^{noncmb} = c_{cement}\alpha_{Build}^{cement}QI_{Build,t}$$

where a^{cement} is cement's share of the Building Materials industry's output, and QI_{Build} is the value of the output of the Building Materials industry (in billion Yuan) which also includes glass and clay products. The emission coefficient (bil. tons of CO2 per billion ¥2014 of fuel j) used in (A46) above is thus given by equations such as this for j=coal:

(A8.21) $$XP_{j=coal}^{CO2} = c_{coal}e_{coal}\xi_{mean}^{coal}$$

In some cases we need the carbon embodied in electricity. This coefficient (bil. tons of CO2 per billion ¥2014 of electricity output) is given by the emissions of CO2 per kWh multiplied by the kWh per ¥ of output):

(A.8.21b) $$XP_{elec}^{CO2} = c_{elec}\xi_{mean}^{elect}$$

Total carbon emissions are then the sum of the fossil emissions and non-combustion emissions:

(A8.22) $$EM_{CO2,t} = EM_{CO2,t}^{fos} + EM_{CO2,t}^{noncmb}$$

Carbon emissions at the industry level

The emissions of CO2 by each industry are complicated in that one has to specify which indirect emissions are to be included. Primary emissions refer to those from burning fossil fuels; secondary emissions refer to the embodied carbon in the intermediate goods. In most cases this would only refer to carbon embodied in electricity, i.e. ignoring the carbon embodied in steel and so on. Let $c_{elect,t}$ be the carbon embodied in electricity at time t (bil. ton CO2 per TWh). The CO2 primary (fossil fuel) emissions and embodied input (primary+secondary) emissions are given by:

(A8.23) $$EM_{jt}^{CO2\,fos} = c_{coal} e_{coal} FT_{jt}^{coal} + c_{oil} e_{oil} FT_{jt}^{oil} + c_{gas} e_{gas} FT_{jt}^{gas}$$

(A8.24) $$EM_{jt}^{CO2emb} = EM_{jt}^{CO2\,fos} + c_{elect,t} \xi_t^{elect} A_{elect,jt}$$

Total emissions that j is responsible for includes both embodied input emissions and process emissions:

(A8.24b) $$EM_{jt}^{CO2tot} = EM_{jt}^{CO2emb} + EM_{CO2,jt}^{noncmb}$$

For the calculation of CO2 price effects on commodity prices we need emission coefficients – the tons of CO2 per constant yuan of energy input. In the input-output accounts there are 6 energy commodities – coal mining, crude oil, natural gas mining, refining & coal products, electricity and gas products (distribution). The emissions given by equation A8.19 depends on the fossil fuel quantities given in A8.12; these FT_{jt}^{f} quantities are for f={coal, oil, gas} and depends on these 6 energy commodities. The emission coefficients for inputs into industry *j* are thus:

(A8.25) $$XC_{coal,jt}^{CO2} = \frac{EM_{coal,j,t}^{CO2}}{A_{coal,j,t}} = c_{coal} e_{coal} \xi_{jt}^{coal} \rho_j^{coke\_loss}$$

$$XC_{crude,jt}^{CO2} = \frac{EM_{crude,j,t}^{CO2}}{A_{crude,j,t}} = c_{oil} e_{oil} \xi_{jt}^{crude}$$

$$XC_{natgas,jt}^{CO2} = \frac{EM_{natgas,j,t}^{CO2}}{A_{natgas,j,t}} = c_{gas} e_{gas} \xi_{jt}^{natgas} \rho_j^{gas\_loss}$$

$$XC_{refine,jt}^{CO2} = \frac{EM_{liquids,j,t}^{CO2} + EM_{coke,j,t}^{CO2}}{A_{refine,j,t}} = c_{oil} e_{oil} \xi_{jt}^{refcmb} (1 - \alpha_{ref\_co,j}^{coalpr}) + c_{coal} e_{coal} \xi_{jt}^{coalpr} \alpha_{ref\_co,j}^{coalpr}$$

$$XC^{CO2}_{gasprod,jt} = \frac{EM^{CO2}_{gasprod,j,t}}{A_{gasprod,j,t}} = c_{gas} e_{gas} \xi^{gasprod}_{jt}$$

Local pollutants

Primary emissions of pollutant x from sector j at period t (EM_{jxt}) are produced from fossil fuel combustion and from non-combustion production processes. The combustion emissions are obtained by multiplying the energy input by an emission factor, ψ_{jxft}, while the process emissions are output multiplied by the emission factor, σ_{jxt}. Total emissions from j are thus:

(oldA8.26) $$EM_{jxt} = \sigma_{jxt} QI_{jt} + \sum_f \left(\psi^{old}_{jxft} e_f FT_{jft} \right)$$

(A8.26) $$EM_{jxt} = \sigma_{jxt} QI_{jt} + \sum_f \left(\psi_{jxft} FT_{jft} \right) \qquad j=1,\ldots,33$$

x = PM_{25}, PM_{10}, SO_2, NO_X, f = coal, oil, gas

where QI_j is the output of industry j's (in billion constant Yuan2014) and FT_j is the quantity of fuel f combusted by industry j. The combustion emission factor (ψ_{jxft}) is given in tons of emissions of pollutant x per ton of fuel, while the process emission factor (σ_{jxt}) is given in tons of primary emissions of pollutant x per billion Yuan of industry output.

Households' use of fuels also generate pollutants:

(A8.27) $$EM_{HH,xt} = \sum_f \left(\psi_{HH,xft} FT_{HH,ft} \right)$$

The estimation of emissions in 2007 is reported in *Clearer Skies* (Chapters 4-6) and an updated version for 2014 is used to calibrate these emission factors. The emission factors are projected based on planning documents of the NDRC and other government agencies.

The emissions are then used by the GEOS-Chem atmospheric model to compute the concentration of various criteria pollutants at each grid cell as described in *Clearer Skies* (Chapter 7). We consider the impact of PM and ozone on human health, and concentrate on the main effects – mortality risks, hospital admission due to cardiovascular reasons and due to respiratory reasons, and outpatient visits. The health effect h due to a change in concentration of pollutant x (ΔC_x) induced by a policy change is given by (*Clearer Skies* Chap. 8):

(A8.28) $$\Delta HE_{hx} = f_{hx}(\Delta C_x) \times Pop \times BI_h; \quad x=PM_{25}, O_3$$

where ΔHE_h denotes the change in the number of cases of health endpoint *h*; *f* is the C-R function ; *Pop* represents the population exposed to the pollutant; and BI_h represents the baseline incidence of the health endpoint *h*. The total impact, say for mortality, is the sum over all pollutants for *h* = mortality, $\Delta HE_h = \sum_x \Delta HE_{hx}$.

We also consider the impact of ozone on agriculture output. There is less agreement in the literature about how to model this impact, and as discussed in *Clearer Skies* (Chap. 8) we use three different measures of ozone exposure (indices I^i_{O3} , i=SUM6, AOT40, W126), to compute the impact on the output of maize, rice and wheat. The percentage change in yields is given by:

(A8.29) $\Delta q_{crop,\mathrm{O3}} = \dfrac{\Delta Q_{crop}}{Q_{crop}} = f_{O3}(\Delta I^i_{O3}) \times Q_{crop} \times BI_{crop}$;   crop=rice, wheat, maize

The final step is to calculate the monetary value of these damages. The value is given by the health impact from (A8.26) multiplied by the willingness to pay value of each type of health effect (V_{ht}), and the value of crop damages is the value of the crop ($V_{crop,t}$) multiplied by the percentage change in crop yields:

(A8.30) $$V_t^p = \sum_h \Delta HE_{ht} V_{ht} + \sum_{crop} V_{crop,t} \Delta q_{crop,t}$$

A1.9 Policy Cases

In policy scenarios we may introduce a new tax, or a new quantity constraint such as emission limits. Policy packages usually come as a complex set of changes, e.g. an emission limit accompanied by subsidies and permit prices. Here we describe how the base case equations are modified to incorporate these changes.

In the emissions trading system (ETS), the government may choose to allocate some free permits to the covered industries to compensate them for having to pay for emission permits. Some examples of these free quota allocations were given above in eq. (A54,57,58). If these free quotas (non-auctioned quotas) are given exogenously as in (A57), then we add that to the profit expression (A2):

(A9.1) $$profit_{jt} = \overline{PI}_{jt}\,\overline{QI}_{jt} + \tilde{PI}_{jt}\,\tilde{QI}_{jt} - \tilde{P}^{KD}_{jt}\tilde{KD}_{jt} - PL_{jt}LD_{jt} - PT_{jt}TD_{jt}$$

$$-\sum_i \overline{PB}_{ij}\ \bar{A}_{ij} - \sum_i \tilde{PB}_{ij}\ \tilde{A}_{ij} + tx^u_{CO2,t} AL^{CO2}_{jt} \quad .$$

If the non-auctioned permit value is given back as output subsidies then we have eq. (A58).

We have defined household utility over a set of consumption commodities. Social welfare may, however, be defined over private and public consumption. To simplify the comparison of welfare between the no-policy base case and the policy case we often keep public expenditures at base case levels, so that private utility comparisons are sufficient to rank welfare outcomes. To do this we have equation (A62) where the real index of government expenditures is set to the base case values, GG_t^{Base}.

Different instruments may be chosen to hit this public expenditure target. The simplest is a lump sum tax/transfer to households, *TLUMP*. Eq. (A26) and (A41) are then modified to be:

(A9.2) $Y^p = YL + DIV + G\_I + G\_transfer + R\_transfer - FEE - TLUMP$

(A9.3)
$$Rev = tax(k) + t^L PL.LS + t^V \sum_j (P_j^{KD} KD_j + PL_j LD_j + PT_j TD_j)$$
$$+ \sum_j t_j^t PI_j QI_j + \sum_j t_j^{res} PI_j QI_j + R\_CON + \sum_i t_i^r PM_i^* M_i$$
$$+ R\_EXT + R^{ETS} + FEE + FEE^{ent} + TLUMP$$

Alternatively, one may change certain tax rates. For example, if we wish to offset new carbon tax revenues by cutting the VAT and capital income tax proportionately, we would multiply the base rates by an endogenous tax scaling factor:

(A9.4) $t_t^V = \lambda_t^{taxscale} t_{t;Base}^V$; $\qquad t_t^K = \lambda_t^{taxscale} t_{t;Base}^K$

In the ETS policy, if there are revenues from emission permit auctions then these would be part of total R^{ETS}, and available for these offsetting tax cuts. The non-auctioned portion is spent on subsidies as given in (A58b).

The above equations describe the situation where the carbon price is given exogenously. In the cases where we have a particular target for CO2 emissions from the ETS sectors, this would be chosen endogenously. To implement this, we introduce an endogenous scaling variable, λ_t^{tco2}, that multiplies an initial guess of a linear carbon price path:

(A9.4b) $\qquad tx^u_{CO2,t} = \lambda_t^{tco2} tx^{u0}_{CO2,t} = \lambda_t^{tco2}(a_0 + b_0 t) P_t^{GDP}$

A.9.2 Hybrid ETS-carbon-tax policy

In the hybrid policy where the ETS covered sectors pay for emission permits represented by eq. (A47), the non-covered sectors pay a carbon tax. In policy Hybrid-1 where the electric sector gets an output subsidy to compensate for the ETS requirements, the covered sectors continue to suffer a double counting of CO2 embodied in electricity, as in eq (A47b). In setting the carbon tax rate we chose the simplest case where the carbon tax rate is equal to the permit price; this means the following modification of eq. (A47) in the pure ETS policy:

(A9.5) $PB_{ijt} = PS_{it} + t_{ijt}^{x,CO2}\ \rho_{ij}^{cmb} \qquad i \in I_{COM}^{CO2}$ ={coal, oil mining, gas mining}

$$t_{ijt}^{x,CO2} = \begin{cases} t_{it}^{x,CO2} & j \in \text{covered industry} \\ t_{it}^{x,CO2} & otherwise \end{cases}$$

$$t_{it}^{x,CO2} = tx_{CO2,t}^{u} XP_i^{CO2}$$

The households also pay the carbon tax (eq A47c):

(A9.6) $P_{it}^{C,IO} = (1+t_{it}^{c})PS_{it} + t_{i,hh,t}^{xCO2}$

In the Hybrid-1 policy, the non-ETS sectors do not have to pay for the embodied carbon:

(A9.7) $PB_{elec,jt} = PS_{elec,t} + tx_{elec,jt}^{x,CO2} \qquad i = elect, \quad j \in$ covered industry

$$tx_{elec,jt}^{x,CO2} = tx_{CO2,t}^{u} XP_{elec}^{CO2}$$

(A9.8) $PB_{elec,jt} = PS_{elec,t} \qquad j \in$ non ETS industry

The subsidy policy in Hybrid-1 follows that of the pure ETS case in eq. (A56):

$$s_{jt}^{CO2} = s_t^{CCOV}\theta_{j0}^{CO2}$$

The revenue due to the emission permits and carbon taxes are:

(A9.9)
$$\begin{aligned} R_t^{ETS} + R_t^{Ctax} &= [\sum_{i\in I_{COM}^{CO2}} \sum_{j\in Covered} t_{ij}^{xCO2}\rho_{ij}^{cmb}A_{ij} + \sum_{j\in Covered}(t_{elec,j}^{xCO2}A_{elec,j} + t_j^{xpu}QI_j)] \\ &\quad +[\sum_{i\in I_{COM}^{CO2}} \sum_{j\in nonETS} t_{ij}^{xCO2}\rho_{ij}^{cmb}A_{ij} + \sum_i t_{i,hh}^{x,CO2}C_i] \\ &= \sum_{i\in I_{COM}^{CO2}} \sum_j t_{ij}^{xCO2}\rho_{ij}^{cmb}A_{ij} + \sum_{j\in Covered}(t_{elec,j}^{xCO2}A_{elec,j} + t_j^{xpu}QI_j) + \sum_i t_{i,hh}^{x,CO2}C_i \end{aligned}$$

In the Hybrid-2 policy we do not give the electricity sector an output subsidy and instead, not require the ETS-covered sectors to include embodied CO2 in their cap. The non-covered sectors have to pay the new price of electricity that would change as a result of the emission permit requirements for power generation. We thus have (A9.5) as above for fossil fuel prices, but replace the electricity price (A9.7, 9.8) with:

(A9.10) $$PB_{elec,jt} = PS_{elec,t} \qquad \text{all } j$$

The subsidy policy in Hybrid-2 becomes:

(A9.11) $$s_{jt}^{CO2} = s_t^{CCOV}\theta_{j0}^{CO2} \qquad j \in \text{covered industry, except electricity}$$

$$s_{elect,t}^{CO2} = 0$$

The revenues from the ETS and carbon taxes add to:

(A9.12)
$$\begin{aligned} R_t^{ETS} + R_t^{Ctax} &= [\sum_{i \in I_{COM}^{CO2}} \sum_{j \in Covered} t_{ij}^{xCO2}\rho_{ij}^{cmb}A_{ij} + \sum_{j \in Covered} t_j^{xpu}QI_j)] \\ &\quad +[\sum_{i \in I_{COM}^{CO2}} \sum_{j \in nonETS} t_{ij}^{xCO2}\rho_{ij}^{cmb}A_{ij} + \sum_i t_{i,hh}^{x,CO2}C_i] \\ &= \sum_{i \in I_{COM}^{CO2}} \sum_j t_{ij}^{xCO2}\rho_{ij}^{cmb}A_{ij} + \sum_{j \in Covered} t_j^{xpu}QI_j) + \sum_i t_{i,hh}^{x,CO2}C_i \end{aligned}$$

A.2 Parameters, exogenous variables and data sources

The key input into the model is the Social Accounting Matrix (SAM) for 2014. This traces the flow of commodities and payments among the producers, household, government and rest of the world. The SAM is assembled from the 2014 input output table which was derived from the 2012 benchmark IO table[5]. A summary of this SAM is given in Figure A1, the actual matrix used is disaggregated to the 33 sectors and commodities. From this we derive the labor and capital incomes, the tax revenues for each type of tax, the expenditures on specific commodities by the household, government and foreign sectors, and government payments of all types in equation (A50).

These payments are combined with employment and capital input data to give the compensation rates for labor and capital for each sector. The estimates for employment by sector are taken from a productivity study of China by Wu et al. (2015) that supplements the official data with labor force surveys. The various tax and subsidy rates are not statutory rates but are implied average rates derived by dividing revenues by the related denominators – values of industry output, capital income, total value added, and imports.

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 may of course be endogenous (i.e. they interact among each other) but we ignore this and specify them independently.

The assumption that affects the growth rate the most is the household savings rate, s_t. Our assumption is to have s_t beginning at the observed 38.9% for 2014 and gradually falling to 30.8% in 2020 and 22.6% in 2030. National private savings is household savings plus the retained earnings of enterprises. The share of retained earnings is assumed to fall, and dividend payouts to rise to reflect the diminishing role of state enterprises in the economy. The dividend rate, i.e. the share not used for retained earnings, was 41.7% in 2014 and we project it to rise to 53% by 2020. It should be pointed out that national savings and investment in the Chinese data includes capital

[5] The input-output table is given in NBS (2016). The benchmark IO table for 2012 is derived from detailed enterprise data, the 2014 IO table is extrapolated by using industry output data and trade data.

such as roads and other public infrastructure, items that are excluded from the "gross fixed private investment" item in the National Accounts of most other countries.

In previous versions of the China Model we expressed the labor supply equation as a product of the working-age population, annual average hours and quality. In this version we use the detailed labor data by demographic groups (sex, age, educational attainment) used by Wu et al. (2015) to construct an effective labor input index. We combine the 2010 labor data with population projections by age groups taken from projections made by the Population Division of the Department of Economic and Social Affairs of the United Nations Secretariat[6]. 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 age. This quality of labor input index was estimated by Wu et al. to have grown at 2.0% per year for the period 1980-2010, with the fastest growth after 2000. As the younger workers who are better educated replace the retiring older workers, China's aggregate labor quality will continue to rise, but at a diminishing rate. By 2020 the quality index is projected to grow at only 0.19% per year. For comparison, the U.S. labor quality growth peaked at 0.5% during the 1960s, and fell to 0.22% per year during 1995-2000 (Jorgenson, Ho and Samuels, 2015).

Total labor hours depend also on the participation rate (retirement rate) and annual working hours. There is no comprehensive data on the number of hours worked and based on comparisons to other countries we project it to rise due to improvements in the functioning of the labor market -- lower underemployment, seasonal unemployment and other labor market frictions. We assume that hours worked per capita rises at 0.5% per year initially but slowing down over time. The results are plotted in Figure A2.

The health effects of air pollution depend to a large degree on the size of the urban population, i.e. the population exposed to the high levels of pollution concentration. Urbanization has been rising rapidly over the past three decades and is expected to continue to rise. The Development Research Center (DRC 2016) gives a projection of the urbanization and this is plotted in Figure A3.

An adjustment for improvements in future capital "quality," or composition, is also made (the ψ_{jt}^{K} coefficient in A85). Cao et al. (2009) note how the composition of the capital stock in

[6] The demographic projections are from *World Population Prospects: the 2015 Revision* downloaded from the U.N. web site, https://esa.un.org/unpd/wpp/.

China has shifted towards assets with shorter life, i.e. towards a smaller share of structures and a larger share of equipment such as computers. They explain how assets which have shorter useful lives generate higher annual capital services per dollar of capital stock, and hence is of a higher quality in the terminology of Jorgenson, Ho and Stiroh (2005). We project that capital quality rises by 2% per year initially, then gradually decelerating. For land, the supply of land for agriculture, oil mining and gas mining is simply set fixed for all periods equal to the base year value.

Tax rates are set equal to those for 2014 derived from the SAM. These are summarized in Table A2. For the government deficit, ΔG, we set it at the base year 1.80% of GDP initially, declining steadily towards zero in the long run. These deficits are cumulated into the stocks of domestic and foreign debt, B_t and B_t^{G*}, assuming a constant division between domestic and foreign borrowing. Data for the stock of debt and interest paid on it comes from the China Statistical Yearbook (2014, Table 7-7, 7-8) and the 2014 Social Accounting Matrix. Government transfers, $G\_transfer$, are set to rise in proportion with population and average wage. The nontax fees paid by households are set to be a fixed share of GDP equal to the base year's share (Table A2).

The current account balance has swung to a huge surplus in the recent years. There is no consensus about the future evolution of this variable, for simplicity, and after setting it as a share of GDP at the observed sample period values, we set it to decline rapidly to zero. This CA_t deficit is also the assumed rate of borrowing from the world. Import prices, PM^{i*}, are assumed fixed at the base year value for every period with one important exception. World oil price forecasts are taken from the U.S. Energy Information Administration and shown in Figure A4[7]. The model also requires estimates of world demand for Chinese exports, EX_{it}. In line with recent Chinese experience, we project a rather high rate of growth of exports, beginning at a 7% growth rate and falling gradually.

The base year data for 2014 was constructed in 2016, since then, the macro variables for 2015-16 is now available; these include the GDP, investment and current account surplus. We take these into account in setting the savings rate and current account balance as share of GDP for these years.

[7] The projections for crude oil prices are taken from the EIA's *Annual Energy Outlook 2016*, which is available on their web page: http://www.eia.doe.gov/oiaf/aeo/supplement/stimulus/regionalarra.html.

Parameters

The rate of productivity growth is another factor that has a large effect on the base case growth rate of the economy but has little impact on the difference between cases. Total Factor Productivity growth at the industry level in the 1982-2010 period show a very wide range of performance as estimated by Wu et al. (2015), ranging from -10% to 5% per year. Cao et al. (2009) gave the Domar-weighted productivity growth for all industries at 2.7% for 1982-2000. To keep the base case as simple as possible we ignore this wide range of observed TFP growth, and in our projections of sector productivity terms in eqn. (A4) we initially set all the g_{jt}'s to the same value. These are then adjusted to match actual GDP growth rates in the initial years for which we have actual data.

The value share parameters of the production functions (α_{Kj}, α_{Lj}, etc.) are set to the values in the 2014 IO table in the first year of the simulation. For future periods we change most of these parameters so that they gradually resemble the shares found in the US input output table for 2007. The exceptions to this are the coal inputs for all the sectors, this is set to converge to a value between current Chinese and US2007 shares [8]. The rate of reduction in energy use is calibrated to the projections in IEA (2016) out to 2040.

The α_{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 2014 Social Accounting Matrix, and for the future periods they gradually approach US 2007 shares except for coal. This implies a higher projected demand for private vehicles and gasoline than that assumed in most other models of China. The coefficients determining demand for different types of investment goods (α_{it}^{I}), and different types of government purchases (α_{it}^{G}), are projected identically.

Given the lack of estimates for trade elasticities for China we turn to the values in the GTAP dataset, the σ^{m} coefficients in the import demand functions are set to values in the range

[8] We have chosen to use U.S. patterns in our projections of these exogenous parameters because they seem to be a reasonable anchor. While it is unlikely that China's economy in 40 years time will mirror the U.S. economy of 2007, it is also unlikely to closely resemble any other economy. Other projections, such as those by the World Bank (1994), use the input-output tables of developed countries including the U.S.

of 1.2 to 4.4. The σ^e coefficients in the export function (A78) are set to values between -2.1 and -3.5. The base share of exports and imports are taken from the SAM.

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Table A1. Selected Parameters and Variables in the Economic Model

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

Table A2. Miscellaneous Tax Rates and Coefficients

Tax rate on capital income	tk	0.0948
Indirect tax rate on output	tt	-0.004 to 0.074
VAT rate	tv	0 to 0.189
Import tax rate	tr	0 to 0.14
Nontax payment share	γ^{NHH}	0.0109
Govt transfer rate	γ^{tr}	0.2576
Household savings rate (2005)		0.3562
Dividend payout rate (2005)		0.4061

Table A3. Industries in China Model, 2014.

		Gross output (bil yuan)	Value added (bil yuan)	Workers (mil)
1	Agriculture	10151	6388	194.348
2	Coal Mining	2183	928	7.752
3	Oil Mining	955	566	0.925
4	Natural Gas Mining	224	112	0.182
5	Non-energy mining	1961	751	4.336
6	Food mfg.	10743	1720	12.482
7	Textiles	4341	677	14.606
8	Apparel, leather	3616	659	18.429
9	Sawmills and furniture	2362	399	7.694
10	Paper, printing, recording media	3807	708	5.901
11	Petroleum processing	4320	375	0.993
12	Chemicals	14470	2279	17.949
13	Nonmetal mineral products	6050	1129	8.426
14	Primary metals	12048	1734	5.687
15	Metal products	4120	667	7.950
16	Machinery	8478	1494	11.945
17	Transportation equipment	8266	1445	6.943
18	Electrical machinery	6305	938	11.093
19	Comm. equip, computer, electronic	8055	1347	12.417
20	Water utilities	362	146	0.750
21	Other manufacturing, recycling	814	437	6.756
22	Electricity, steam	3778	1346	3.467
23	Gas utilities	473	88	0.183
24	Construction	16709	4114	61.499
25	Transportation svc	7429	2777	22.484
26	Telecommunications, Software and IT	3321	1564	4.828
27	Wholesale and Retail	8924	4679	77.399
28	Hotels and Restaurants	2714	1065	24.063
29	Finance	7737	4380	14.464
30	Real estate	5070	3417	11.971
31	Business services	8991	3075	17.499
32	Other services	8613	4782	131.390
33	Public administration	3934	2370	45.715

Figure A1. Summary Social Accounting Matrix for China, 2014 (bil yuan)

Receipts \ Expend.	Commodity	Industry	Labor	Capital	Land	House-holds	Enterprise	VAT+BT	Govt	Tariff	ROW	Capital account	Total
Commodity		129452				24120			8591		15048	29169	206380
Industry	191324												191324
Labor		27454											27454
Capital		24030											24030
Land		2183											2183
Households			27454	0	2130		8056		2751		-168		40223
Enterprise				24030	53						-199		23884
VAT+BT		4888											4888
Government		3318				738	4584	4888		1741	0	1142	16410
Tariff	1741												1741
ROW	13314		0	0					18				13332
Capital a/c						15366	11245		5050		-1349		30311
Total	206380	191324	27454	24030	2183	40223	23884	4888	16410	1741	13332	30311	
Addendum:	GDP=	63614											

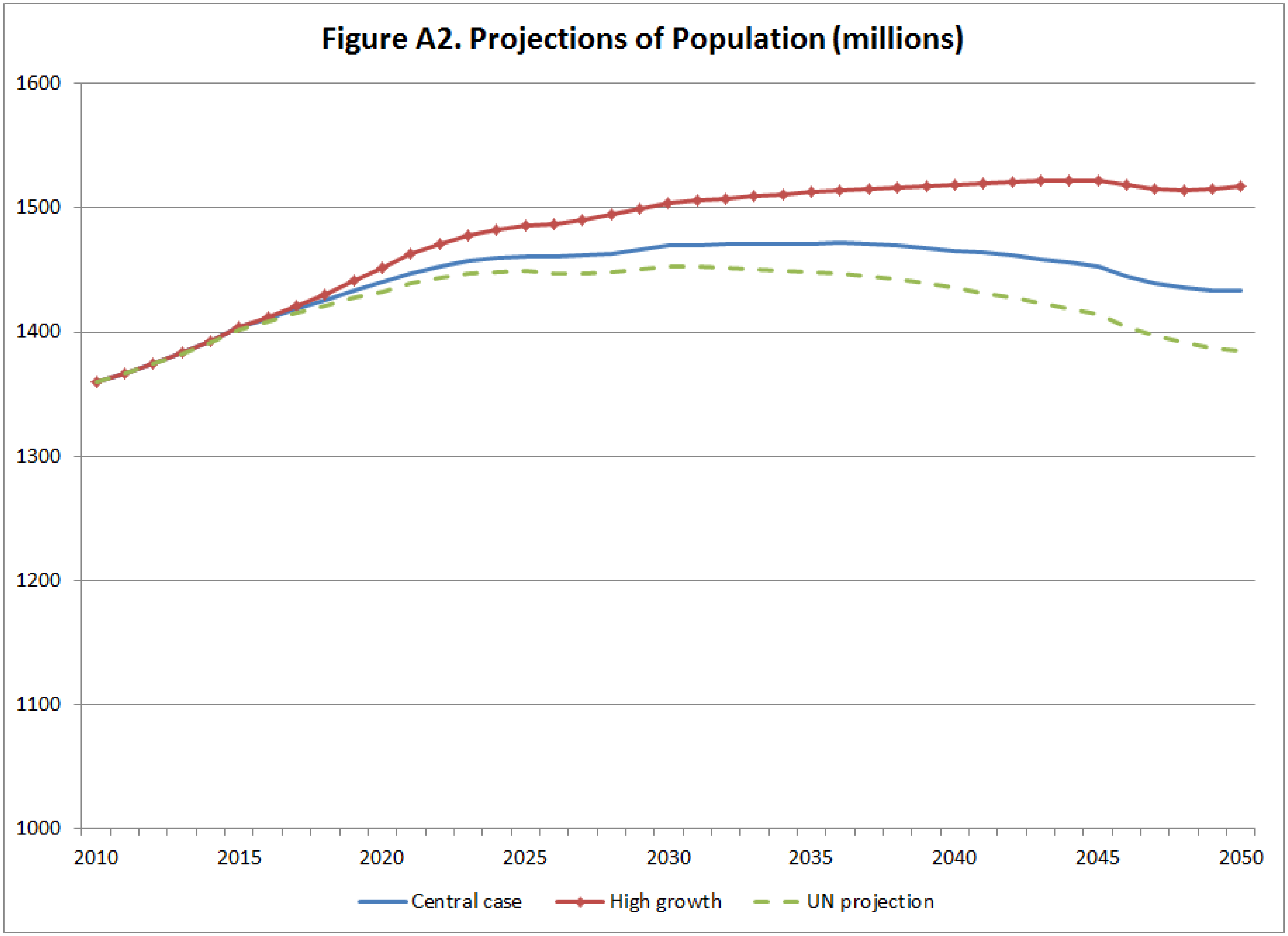


Figure A2. Projections of Population (millions)
1600
1500
1400
1300
1200
1100
1000
2010
2015
2020
2025
2030
2035
2040
2045
2050
Central case
High growth
UN projection

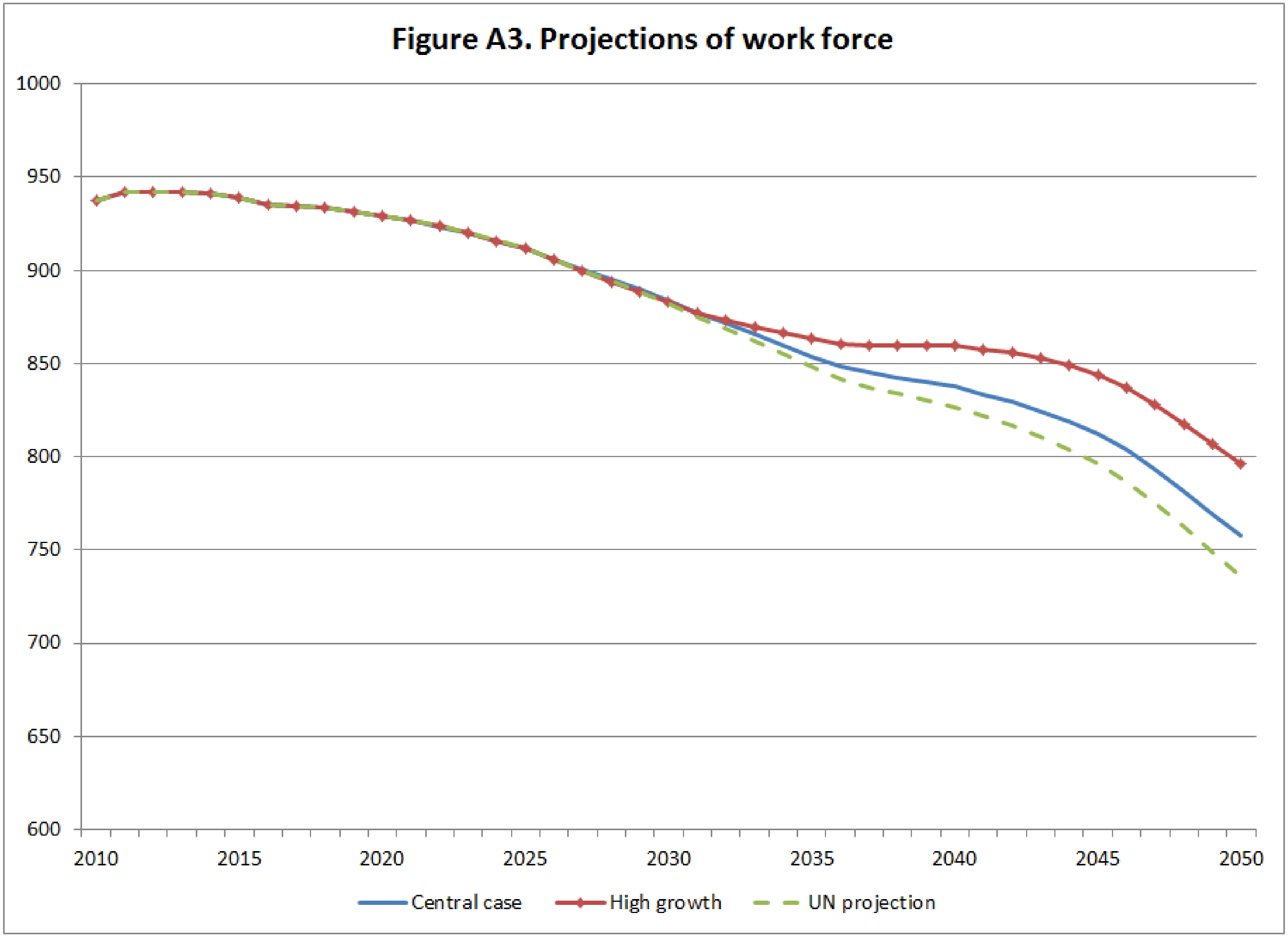
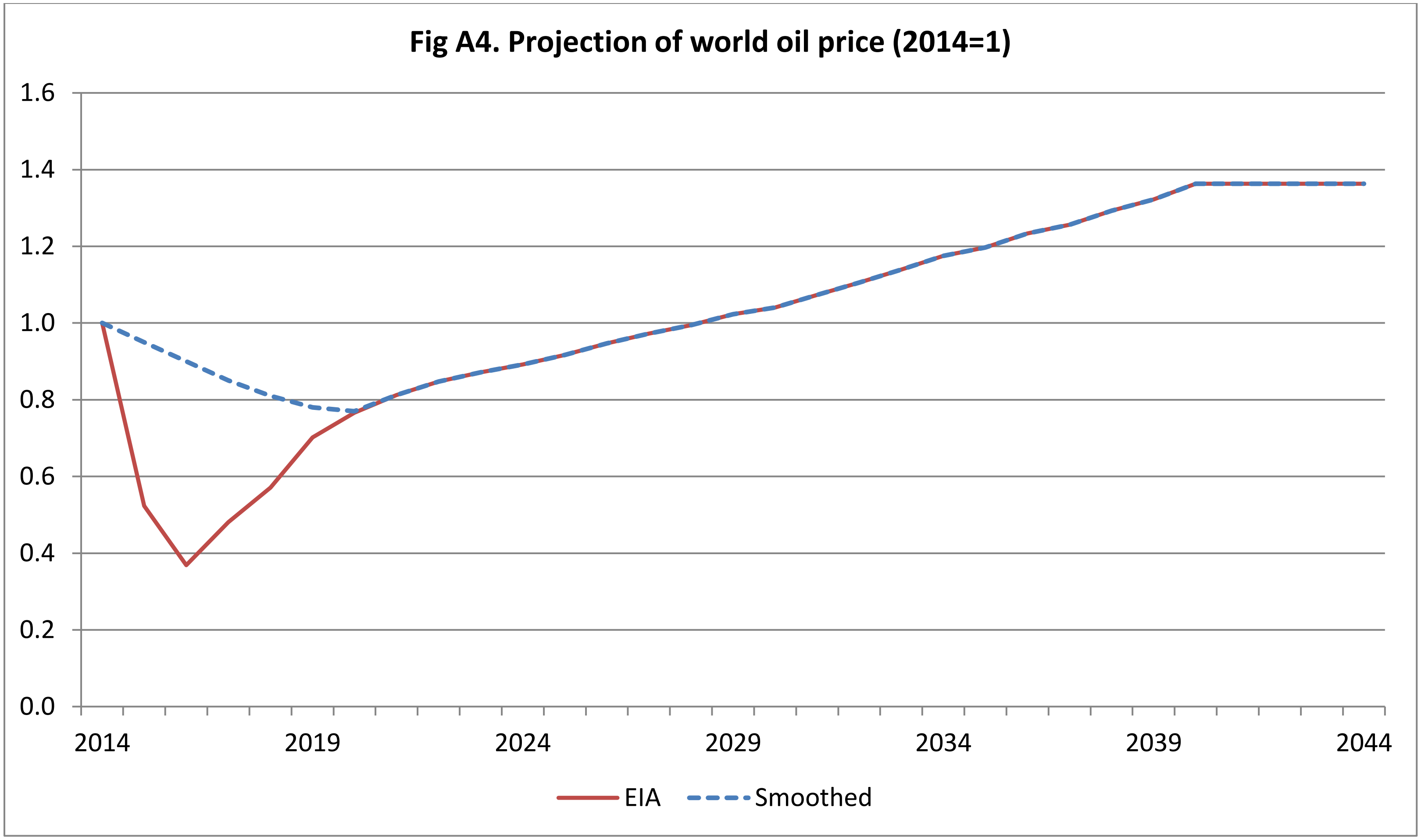


Figure A3. Projections of work force
1000
950
900
850
800
750
700
650
600
2010
2015
2020
2025
2030
2035
2040
2045
2050
Central case
High growth
UN projection



Note: Projection taken from US EIA(2013).

Symbol	GAMS variable name
i	com
j	j, traJ, nontraJ

x	xtr
PI	PO
PI_j^t	PIm(j)
$P_j^{KD} KD_j - D_j$	CF(j)
θ_{j0}^{CO2}	tsCO2_int(traJ)
tx_x^u	tx_xu(xtr)
t_j^{xu}, t_j^x	tx_u(j), tx_v(j)
t_i^{rxu}	tr_xu(com)
$tx_{CO2,t}^u$	tt_xu(xtr=CO2)
t_i^{xCO2}	tt_u(com)
$t_{i,hh}^{xCO2}$	tt_tax(com)
$tx_{elec,j}^{xCO2}$	tt_elect
s_t^{CCOV}	tsco2_scale
XP_{elec}^{CO2}	XP_elect*xi_elec_out/1000
t_j^{xpu}	tx_process(traJ)
$XP_{cement}^{procCO2}$	c_cement
α_{NMM}^{cement}	cement_shr
R_t^{ETS}	R_CO2
$G_t^{ETS\_SUB}$	sum(j, tsCO2_scale*tsCO2_int(j)*POm(j)QI(j))
α_t^{CO2auc}	auction_shr