ECONONOMIC POLICY

RESEARCH PAPER SERIES

# A CGE MODEL FOR LIAONING PROVINCE

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# RESEARCH PAPERS ON ECONOMIC DEVELOPMENT

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## 1.Introduction

This document presents a regional CGE model for the Liaoning Province as an analytical tool. The prototype of the regional model has the following key features:

- Labor markets disaggregated by skill level: skilled and unskilled
- A production structure which differentiates the substitutability of unskilled labor on the one hand, and skilled labor and capital on the other hand
- Detailed income distribution
- Transfers from central and local government, and remittances
- Differentiation of urban and rural households
- A tiered structure of trade (differentiating between international and domestic trading partners)

The rest of the document proceeds to describe the model in detail using the standard circular flow description of the economy. It starts with production (*P*), income distribution (*Y*), demand (*D*), trade (*T*), transport margins (*M*), goods market equilibrium (*E*), macro closure (*C*), factor market equilibrium (*F*), macroeconomic identities (*I*), and growth (*G*).

Table 1 describes the indices used in the equations. Note that the model differentiates between production activities, denoted by the index *i*, and commodities, denoted by the index *k*. In many models, the two will overlap exactly. However, this differentiation allows for the same commodity to be produced by one or more sectors, and to differentiate these commodities by source of production.

**Table 1 Indices used in the model**

| | |
|---|---|
| *i/j* | Production activities |
| *k* | Commodities |
| *l* | Labor skills |
| *ul* | Unskilled labor |
| *sl* | Skilled labor [a] |
| *kt* | Capital types |
| *lt* | Land types |
| *nr* | Natural resources |

| | |
|---|---|
| *e* | Corporations |
| *h* | Households |
| *f* | Other Final demand accounts in addition to households [b] |
| *m* | Trade and transport margin accounts [c] |
| *r* | International trading partners |
| *dr* | Domestic trading partners |

*Notes*:

a. The unskilled and skilled labor indices, *ul* and *sl*, are subsets of *l*, and their union composes the set indexed by *l*.

b. The standard final demand accounts are '*Extrasystem*' for Extra-budget corporation fees, '*Locgov*' for local government, '*Cengov*' for central government, '*Capacc*' for public investment, and '*Inventory*' for changes in stocks.

c. The standard trade and transport margin accounts are '*D*' for domestic goods, '*M*' for imported goods, and '*X*' for exported goods.

## 2.Model Equations[1]

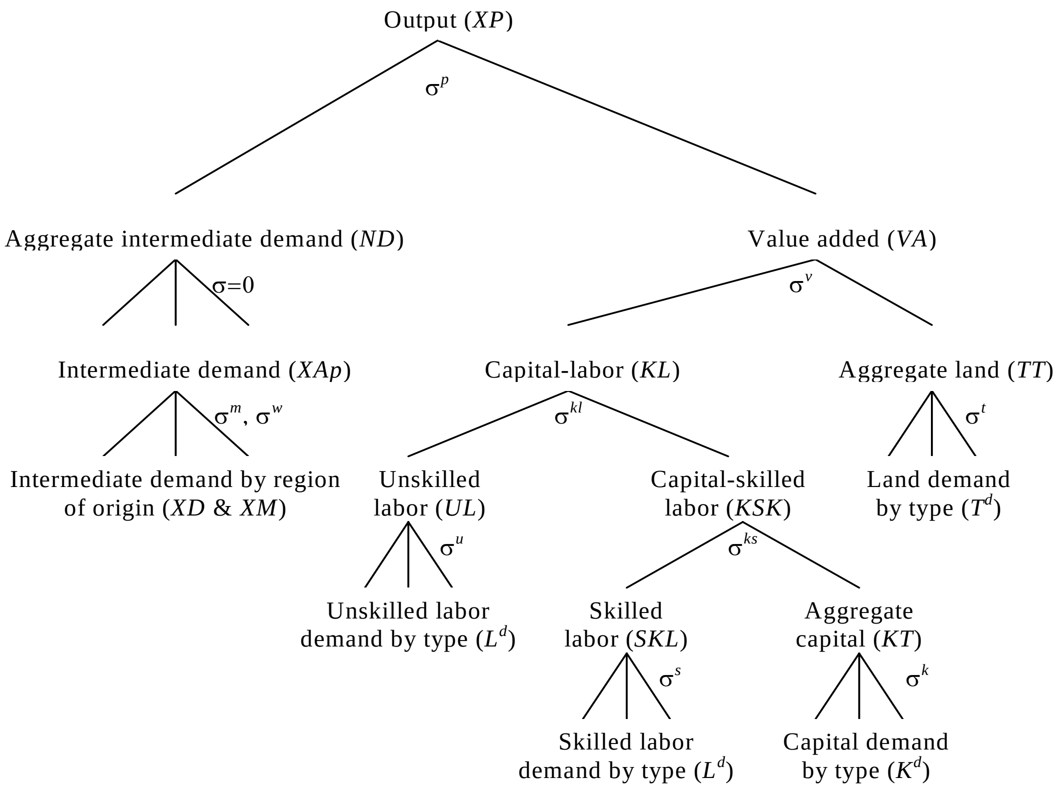
As for the production structure in the model, there are multiple types of capital, land and labor. They are combined in a nested-CES structure which is intended to represent the various

[1] As for the equations description, if the equation is somewhat different from that of the prototype model, then its serial number will be in green color; if the equation is added on the basis of the prototype model, then its serial number will be in red color.

substitution possibilities across these different factors of production. Typically, intermediate goods will be entered in fixed proportion to output, though at the aggregate level, the model allows for a degree of substitutability between aggregate intermediate demand and value added. The decomposition of value added, has several components as shown by *figure* 1 for a representation of the multiple nests. First, land is assumed to be a substitute for an aggregate capital labor bundle.[2] The latter is then decomposed into unskilled labor on the one hand and skilled labor capital on the other hand. This conforms to recent observations which suggest that capital and skilled labor are complements which can substitute for unskilled labor. The four aggregate factors—unskilled and skilled labor, land and capital, are decomposed by type in a final CES nest.

**Figure 1 Nested structure of production**

2 In some sectors the model also allows for a sector-specific factor of production, for example, coal mining and oil production require reserves which cannot be used for any other activity. In this case, the nesting follows the same general structure as depicted in Figure 1.




## 2.1. Top-level nest and producer price

The top-level nest has output, *XP*, produced as a combination of value added, *VA*, and an aggregate demand for goods and non-factor services, *ND*. In most cases, the substitution elasticity will be assumed to be zero, in which case the top-level CES nest is a fixed-coefficient Leontief production function. Equations (P-1) and (P-2) represent the optimal demand conditions for the generic CES production function, where *PND* is the price of the *ND* bundle, *PVA* is the aggregate price of value added, *PX* is the unit cost of production, and $\sigma^p$ is the substitution elasticity. If the latter is zero, both *ND* and *VA* are used in fixed proportions to output, irrespective of relative prices. Equation (P-3) represents the unit cost function, *PX*. It is derived from the CES dual price formula. The model assumes there is constant-returns-to-scale and perfect competition in all sectors. Hence, the producer price, *PP*, is equal to the unit cost adjusted for certain tax/subsidy. The taxes include local and central production taxes/subsidies, local and central business taxes, and extra-budget corporation fees, with the relevant tax rate $pptx_i^l$ , $pptx_i^c$ , $pbtx_i^l$ , $pbtx_i^c$ and $\tau_i^{cfee}$ .

$$ND_i = \alpha_i^{nd} \left( \frac{PX_i}{PND_i} \right)^{\sigma_i^p} XP_i \qquad \text{P-1}$$

$$VA_i = \alpha_i^{va} \left( \frac{PX_i}{PVA_i} \right)^{\sigma_i^p} XP_i \qquad \text{P-2}$$

$$PX_i = \left[ \alpha_i^{nd} PND_i^{1-\sigma_i^p} + \alpha_i^{va} PVA_i^{1-\sigma_i^p} \right]^{1/(1-\sigma_i^p)} \qquad \text{P-3}$$

$$PP_i = \left(1 + pptx_i^l + pptx_i^c + pbtx_i^l + pbtx_i^c + \tau_i^{cfee}\right) PX_i \qquad \text{P-4}$$

## 2.2. Second-level production nests

The second-level nest has two branches. The first decomposes aggregate intermediate demand, *ND*, into sectoral demand for goods and services, *XAp*. The model explicitly assumes a Leontief structure. Thus equation (P-5) describes the demand for good *k* by sector *j*, where the coefficient *a* represents the proportion between *XAp* and *ND*. The price of the *ND* bundle, *PND*, is the weighted average of the price of goods and services, *PA*, using the technology coefficients as weights, equation (P-6). The so-called Armington price is multiplied by a sector and commodity specific indirect tax, $\tau^{cp}$.

$$XAp_{k,j} = a_{k,j} ND_j \qquad \text{P-5}$$

$$PND_j = \sum_k a_{k,j} \left(1 + \tau^{cp}_{k,j}\right) PA_k \qquad \text{P-6}$$

The second branch decomposes the aggregate value added bundle, *VA*, into three components: aggregate demand for capital and labor, *KL*, aggregate land demand, $TT^d$, and a sector-specific resource, *NR*,[3] see equations (P-7) through (P-9). The relevant component prices are *PKL*, *PTT* and *PR*, respectively, and the substitution elasticity is given by $\sigma^v$. Equation (P-9) allows for the possibility of factor productivity changes as represented by the λ parameter. The price of value added, *PVA*, is the CES aggregation of the three component prices, as defined by equation (P-10).

$$KL_i = \alpha_i^{kl} \left( \frac{PVA_i}{PKL_i} \right)^{\sigma_i^v} VA_i \qquad \text{P-7}$$

$$TT_i^d = \alpha_i^{tt} \left( \frac{PVA_i}{PTT_i} \right)^{\sigma_i^v} VA_i \qquad \text{P-8}$$

$$NR_i^d = \alpha_i^{nr} \left(\lambda_i^{nr}\right)^{\sigma_i^v - 1} \left( \frac{PVA_i}{PR_i} \right)^{\sigma_i^v} VA_i \qquad \text{P-9}$$

$$PVA_i = \left[ \alpha_i^{kl} PKL_i^{1-\sigma_i^v} + \alpha_i^{tt} PTT_i^{1-\sigma_i^v} + \alpha_i^{nr} \left( \frac{PR_i}{\lambda_i^{nr}} \right)^{1-\sigma_i^v} \right]^{1/(1-\sigma_i^v)} \qquad \text{P-10}$$

[3] The latter will typically be zero in most sectors.

## 2.3. Third-level production nests

The third-level nest decomposes the aggregate capital-labor bundle, *KL*, into two components. The first is the aggregate demand for unskilled labor, *UL*, with an associated price of *PUL*. The second is a bundle composed of skilled labor and capital, *KSK*, with a price of *PKSK*. Equations (P-11) and (P-12) reflect the standard CES optimality conditions for the demand for these two components, with a substitution elasticity given by $\sigma^{kl}$. The price of capital-labor bundle, *PKL*, is defined in equation (P-13).

$$UL_i = \alpha_i^u \left( \frac{PKL_i}{PUL_i} \right)^{\sigma_i^{kl}} KL_i \qquad \text{P-11}$$

$$KSK_i = \alpha_i^{ksk} \left( \frac{PKL_i}{PKSK_i} \right)^{\sigma_i^{kl}} KL_i \qquad \text{P-12}$$

$$PKL_i = \left[ \alpha_i^u PUL_i^{1-\sigma_i^{kl}} + \alpha_i^{ksk} PKSK_i^{1-\sigma_i^{kl}} \right]^{1/(1-\sigma_i^{kl})} \qquad \text{P-13}$$

## 2.4. Fourth-level production nests

The fourth-level nest decomposes the capital-skilled labor bundle into a capital component, $KT^d$, and a skilled labor component, *SKL*. Equations (P-14) and (P-15) represent the optimality conditions where the relevant component prices are *PKT* and *PSKL*, and the substitution elasticity is given by $\sigma^{ks}$. Equation (P-16) determines the price of the *KSK* bundle, *PKSK*.

$$SKL_i = \alpha_i^s \left( \frac{PKSK_i}{PSKL_i} \right)^{\sigma_i^{ks}} KSK_i \qquad \text{P-14}$$

$$KT_i^d = \alpha_i^{kt} \left( \frac{PKSK_i}{PKT_i} \right)^{\sigma_i^{ks}} KSK_i \qquad \text{P-15}$$

$$PKSK_i = \left[ \alpha_i^s PSKL_i^{1-\sigma_i^{ks}} + \alpha_i^{kt} PKT_i^{1-\sigma_i^{ks}} \right]^{1/(1-\sigma_i^{ks})} \qquad \text{P-16}$$

## 2.5. Demand for labor by sector and skill

Equations (P-17) and (P-18) decompose the demands for aggregate unskilled and skilled labor, respectively, across their different components. The variable $L^d$ represents labor demand in sector $i$ for labor of skill level $l$. The relevant wage is given by $W$ which is allowed to be both sector and skill-specific. The respective cross-skill substitution elasticities are $\sigma^u$ and $\sigma^s$. Both equations (P-17) and (P-18) incorporate sector and skill specific labor productivity, represented by the variable $\lambda^l$. The aggregate unskilled and skilled price indices are determined in equations (P-19) and (P-20), respectively *PUL* and *PSKL*.

$$L_{i,ul}^d = \alpha_{i,ul}^l \left( \lambda_{i,ul}^l \right)^{\sigma_i^u - 1} \left( \frac{PUL_i}{W_{i,ul}} \right)^{\sigma_i^u} UL_i \qquad ul \in \{\text{Unskilled labor}\} \qquad \text{P-17}$$

$$L_{i,sl}^d = \alpha_{i,sl}^l \left( \lambda_{i,sl}^l \right)^{\sigma_i^s - 1} \left( \frac{PSKL_i}{W_{i,sl}} \right)^{\sigma_i^s} SKL_i \qquad sl \in \{\text{Skilled labor}\} \qquad \text{P-18}$$

$$PUL_i = \left[ \sum_{ul \in \{\text{Unskilled labor}\}} \alpha^l_{i,ul} \left( \frac{W_{i,ul}}{\lambda^l_{i,ul}} \right)^{1-\sigma^u_i} \right]^{1/(1-\sigma^u_i)} \quad \text{P-19}$$

$$PSKL_i = \left[ \sum_{sl \in \{\text{Skilled labor}\}} \alpha^l_{i,sl} \left( \frac{W_{i,sl}}{\lambda^l_{i,sl}} \right)^{1-\sigma^s_i} \right]^{1/(1-\sigma^s_i)} \quad \text{P-20}$$

## 2.6. Demand for capital and land across types

The aggregate land and capital bundles, $KT^d$ and $TT^d$ respectively, are disaggregated across types, leading to type and sector-specific capital and land demand, $K^d$ and $T^d$. The decomposition is represented in equations (P-21) and (P-23), where the respective prices are *R* and *PT* which are both type and sector-specific. The equations also incorporate productivity factors. Equations (P-22) and (P-24) represent the price indices for aggregate capital and land, respectively *PKT* and *PTT.*

$$K^d_{i,kt} = \alpha^k_{i,kt} \left( \lambda^k_{i,kt} \right)^{\sigma^k_i - 1} \left( \frac{PKT_i}{R_{i,kt}} \right)^{\sigma^k_i} KT^d_i \quad \text{P-21}$$

$$PKT_i = \left[ \sum_{kt} \alpha^k_{i,kt} \left( \frac{R_{i,kt}}{\lambda^k_{i,kt}} \right)^{1-\sigma^k_i} \right]^{1/(1-\sigma^k_i)} \quad \text{P-22}$$

$$T^d_{i,lt} = \alpha^t_{i,lt} \left( \lambda^t_{i,lt} \right)^{\sigma^t_i - 1} \left( \frac{PTT_i}{PT_{i,lt}} \right)^{\sigma^t_i} TT^d_i \quad \text{P-23}$$

$$PTT_i = \left[ \sum_{lt} \alpha_{i,lt}^{k} \left( \frac{PT_{i,lt}}{\lambda_{i,lt}^{k}} \right)^{1-\sigma_i^t} \right]^{1/(1-\sigma_i^t)} \qquad \text{P-24}$$

## 2.7. Commodity aggregation

Each activity produces a single commodity, *XP*, indexed by *i*. Consumption goods indexed by *k* is a combination of one or more produced goods. Aggregate domestic supply of goods *k*, *X*, is a CES combination of one or more produced goods *i*. Equation (P-25) represents the optimality condition of the aggregation of produced goods into commodities. The producer price is *PP*, and the price of the aggregate supply is *P*. The degree of substitutability across produced commodities is $\sigma^c$. Equation (P-26) determines the aggregate supply price, *P*. The model allows for perfect substitutability, in which case the law of one price holds and the produced commodities are simply aggregated to form aggregate output.

$$\begin{cases} XP_i = \alpha_{i,k}^{c} \left( \dfrac{P_k}{PP_i} \right)^{\sigma_k^c} X_k & \text{if} \quad \sigma_k^c \neq \infty \\ PP_i = P_k & \text{if} \quad \sigma_k^c = \infty \end{cases} \qquad \text{P-25}$$

$$\begin{cases} P_k = \left[ \sum_{i \in K} \alpha_{i,k}^{c} PP_i^{1-\sigma_k^c} \right]^{1/(1-\sigma_k^c)} & \text{if} \quad \sigma_k^c \neq \infty \\ X_k = \sum_{i \in K} XP_i & \text{if} \quad \sigma_k^c = \infty \end{cases} \qquad \text{P-26}$$

## 2.8. Income distribution

The model has a rich menu of income distribution channels—factor income and intra-household, government and foreign transfers (i.e. remittances). It also includes corporations used as a pass-through account for channeling operating surplus.

### 2.8.1. Factor Income

There are four broad factors—a sector specific resource, land, labor and capital—the latter three which can be sub-divided into various types. Equations (Y-1) through (Y-3) determine aggregate net-income from labor, *LY*, capital, *KY*, and land, *TY*, each indexed by its sub-types. The fourth equation determines aggregate income from the sector-specific resource. These incomes are net incomes because the model incorporates factor taxes. The taxes levied by local government are designated by $\tau_{i,l}^{fll}$ , $\tau_{i,kt}^{fkl}$ , $\tau_{i,lt}^{ftl}$ and $\tau_{i}^{frl}$ respectively, and the taxes levied by central government are designated by $\tau_{i,l}^{flc}$ , $\tau_{i,kt}^{fkc}$ , $\tau_{i,lt}^{ftc}$ and $\tau_{i}^{frc}$ respectively.[4]

$$LY_l = \sum_i \frac{W_{i,l} L_{i,l}^d}{1 + \tau_{i,l}^{fll} + \tau_{i,l}^{flc}} \qquad \text{Y-1}$$

$$KY_{kt} = \sum_i \frac{R_{i,kt} K_{i,kt}^d}{1 + \tau_{i,kt}^{fkl} + \tau_{i,kt}^{fkc}} \qquad \text{Y-2}$$

$$TY_{lt} = \sum_i \frac{PT_{i,lt} T_{i,lt}^d}{1 + \tau_{i,lt}^{ftl} + \tau_{i,lt}^{ftc}} \qquad \text{Y-3}$$

[4] The factor taxes are type- and sector-specific. Note as well that the relevant factor prices represent the perceived cost to employers, not the perceived remuneration of workers.

$$RY = \sum_i \frac{PR_i R_i^d}{1+\tau_i^{frl} + \tau_i^{frc}} \qquad \text{Y-4}$$

### 2.8.2. Distribution of profits

All of labor, land and sector-specific factor income is allocated to households. Profits (aggregated with income from the sector-specific resources), on the other hand, are distributed to four broad accounts, enterprises, households, the rest of the world (ROW) and the rest of main China (ROMC). Equation (Y-5) determines the level of profits distributed to enterprises, $TR^E$. Equation (Y-6) represents the level of profits distributed directly to households, $TR^H$. Equation (Y-7) determines the level of factor income distributed abroad, $TR^W$. And equation (Ya-1) determines the level of income distributed to the rest of main China (ROMC). Note that the four share parameters, $\varphi^E$, $\varphi^H$, $\varphi^W$ and $\varphi^{ROMC}$ sum to unity.

$$TR^E_{k,kt} = \varphi^E_{k,kt} KY_{kt} \qquad \text{Y-5}$$

$$TR^H_{k,kt} = \varphi^H_{k,kt} KY_{kt} \qquad \text{Y-6}$$

$$TR^W_{k,kt} = \varphi^W_{k,kt} KY_{kt} \qquad \text{Y-7}$$

$$TR^C_{k,kt} = \varphi^{ROMC}_{k,kt} KY_{kt} \qquad \text{Ya-1}$$

### 2.8.3. Corporation Income

Corporate income, $TR^E$, is split into five accounts. First, the government (both local and central government) receives its share through the corporate income tax, $\kappa^c$. The residual is split into four: retained earnings, income distributed to households, the rest of the world (ROW) and the rest of main China (ROMC). Equation (Y-8) determines corporate income of enterprise *e*, *CY*. It is the sum, over possible capital types, of shares of distributed profits (to corporations). Equation (Y-9) determines retained earnings, i.e. corporate savings, $S^c$, where the rate of retained earnings is given by $s^c$. Equations (Y-10), (Y-11) and (Ya-2) determine the overall transfers to households, to ROW and to ROMC. Note that the three share parameters, $\varphi^H$, $\varphi^W$, $\varphi^{ROMC}$ and the retained earnings rate, $s^c$, sum to unity.

$$CY_e = \sum_{kt} \varphi^E_{kt,E} TR^E_{k,kt} \quad \text{Y-8}$$

$$S^c_e = s^c_e \left(1 - \kappa^{ccg}_e - \kappa^{c\lg}_e\right) CY_e \quad \text{Y-9}$$

$$TR^H_{c,e} = \varphi^H_{c,e} \left(1 - \kappa^{ccg}_e - \kappa^{c\lg}_e\right) CY_e \quad \text{Y-10}$$

$$TR^W_{c,e} = \varphi^W_{c,e} \left(1 - \kappa^{ccg}_e - \kappa^{c\lg}_e\right) CY_e \quad \text{Y-11}$$

$$TR^C_{c,e} = \varphi^{ROMC}_{c,e} \left(1 - \kappa^{ccg}_e - \kappa^{c\lg}_e\right) CY_e \quad \text{Ya-2}$$

### 2.8.4. Household Income

Aggregate household income, *YH*, is composed of eight elements: labor, land and sector-specific factor remuneration, distributed capital income and corporate profits, transfers from government (both local and central government) and households, and external remittances from ROW and ROMC, as shown in equation (Y-12). Government transfers, in the standard closure, are fixed in real terms and are multiplied by an appropriate price index to preserve model homogeneity. Remittances, are fixed in international currency terms, and are multiplied by the exchange rate, *ER*, to convert them into local currency terms.

Disposable income, *YD*, is equal to after-tax income, less household transfers, equation (Y-13), where the household tax rate is $\kappa^h$. It is multiplied by an adjustment factor, $\lambda^h$, which is exogenous in this model. In the macro-closure of this model, the tax rate and government expenditure are held fixed, and government savings (or deficit) adjust to achieve the given government fiscal balance. Aggregate household transfer, $TR^H$, is a share of after-tax income, equation (Y-14). This is transferred to individual households, rest of the world, and rest of main China, respectively $TR^h$, $TR^w$, and $TR^c$ using constant share equations (Y-15), (Y-16) and (Ya-3).

$$YH_h = \underbrace{\sum_l \varphi^h_{l,l} LY_l}_{\text{Labor}} + \underbrace{\sum_{kt} \varphi^h_{kt,h} TR^H_{k,kt}}_{\text{Capital}} + \underbrace{\sum_{lt} \varphi^h_{lt,h} TY_{lt}}_{\text{Land}} + \underbrace{\varphi^h_{nr,h} RY}_{\text{Sector-specific factor}}$$
$$+ \underbrace{\sum_e \varphi^h_{e,h} TR^H_{c,e}}_{\text{Enterprise}} + \underbrace{PLEV.TR^h_{cg,h} + PLEV.TR^h_{\lg,h}}_{\text{Transfers from government}} \qquad \text{Y-12}$$
$$+ \underbrace{\sum_{h'} TR^h_{h,h'}}_{\text{Intra-household transfers}} + \underbrace{ER.TR^h_{r,h} + PLEV.TR^h_{romc,h}}_{\text{External remittances}}$$

$$YD_h = \left(1 - \lambda^h \kappa^h_h\right) YH_h - TR^H_h \qquad \text{Y-13}$$

$$TR^H_h = \varphi^H_{h,h} \left(1 - \lambda^h \kappa^h_h\right) YH_h \qquad \text{Y-14}$$

$$TR^h_{h,h'} = \varphi^h_{h,h'} TR^H_h \qquad \text{Y-15}$$

$$TR_{h,r}^{w} = \varphi_{h,r}^{w} TR_{h}^{H} \qquad \text{Y-16}$$

$$TR_{h,dr}^{c} = \varphi_{h,dr}^{ROMC} TR_{h}^{H} \qquad \text{Ya-3}$$

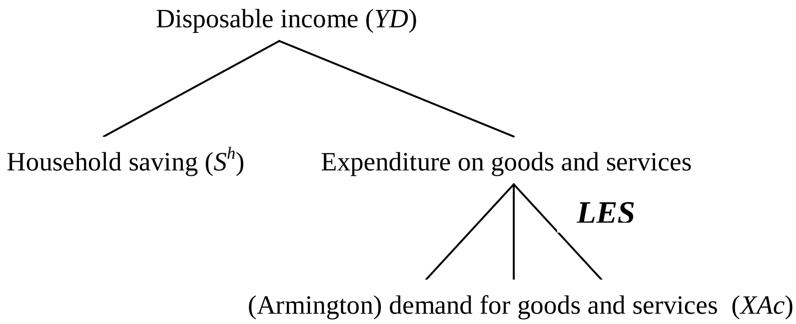
## 2.9. Domestic final demand

Domestic final demand is composed of two broad agents—households and other domestic final demand. The model incorporates urban and rural households. Household demand has a uniform specification, however, with household-specific expenditure parameters. The other domestic final demand categories include government current expenditures, *Locgov* and *Cengov*, private and public investment expenditures, *Capacc*, extra-budget expenditures, *Extrasystem*, and changes in stocks, *inventory*. The other domestic final demand categories, indexed by *f*, are also assumed to have a uniform expenditure function, but with agent-specific expenditure parameters. Demand at the top-level reflects the demand for the Armington good. The latter are added up across all activities in the economy and split into domestic and import components at the national level, and then further split into local and domestic imports at the regional level.

### 2.9.1. Household Expenditures

Households have a tiered demand structure as shown by figure 2.

**Figure 2 Nested structure of consumer demand**




At the top-level, the households save a constant share of disposable income with the savings rate given by $s^h$. At the next level, residual income is allocated across goods and services, *XAc*, using the linear expenditure system (LES). Equation (D-1) represents the LES demand function. Household consumption is the sum of $\theta$, which is referred to as the subsistence minimum, and a share of real supernumerary income. Supernumerary income is equal to residual disposable income, subtracting savings and aggregate expenditures on the subsistence minima from disposable income. The next level, undertaken at the regional level, is the decomposition of Armington demand, *XAc*, into its local and import components. This part will be described in detail in the section of trade. Equation (D-2) determines household saving, $S^h$, by residual. The consumer price index, *CPI*, is defined in equation (D-3). The consumer price is equal to the economy-wide Armington price, *PA*, multiplied by a household and commodity specific ad valorem tax, $\tau^{cc}$.[5]

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$$XAc_{k,h} = \theta_{k,h} + \frac{\mu_{k,h}}{(1+\tau^{cc}_{k,h})PA_k}\left((1-s^h_h)YD_h - \sum_{k'}(1+\tau^{cc}_{k',h})PA_{k'}\theta_{k'}\right) \quad \text{D-1}$$

$$S^h_h = YD_h - \sum_k (1+\tau^{cc}_{k,h})PA_k XAc_{k,h} \quad \text{D-2}$$

[5] In case of this model, the ad valorem tax is zero according to the base SAM of the region.

$$CPI_h = \frac{\sum_k (1+\tau^{cc}_{k,h}) PA_k XAc_{k,h,0}}{\sum_k (1+\tau^{cc}_{k,h,0}) PA_{k,0} XAc_{k,h,0}} \quad \text{D-3}$$

#### 2.9.2. Other domestic demand accounts

The other domestic final demand account for all uses of CES expenditure functions (with the option of having fixed volume or value expenditure shares with an elasticity of 0 or 1, respectively). Equation (D-4) determines the expenditure share on goods and services, *XAf*. Equation (D-5) defines the expenditure price index, *PF*. And equation (D-6) defines the value of expenditures, *YF*.

$$XAf_{k,f} = \alpha^f_{k,f} \left( \frac{PF_f}{(1+\tau^{cf}_{k,f}) PA_k} \right)^{\sigma^f_f} XF_f \quad \text{D-4}$$

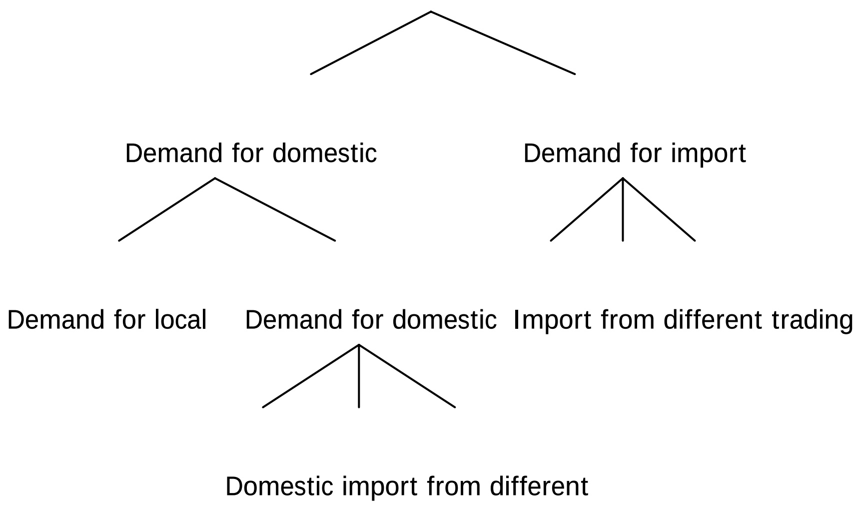
$$PF_f = \left[ \sum_k \alpha^f_f \left( (1+\tau^{cf}_{k,f}) PA_k \right)^{1-\sigma^f_f} \right]^{1/(1-\sigma^f_f)} \quad \text{D-5}$$

$$YF_f = PF_f XF_f \quad \text{D-6}$$

### 2.10. Trade equations

This section demonstrates the model of trade, including both international and domestic trade. The import is depicted using a tiered structure shown by figure 3.

**Figure 3 Import Structure**

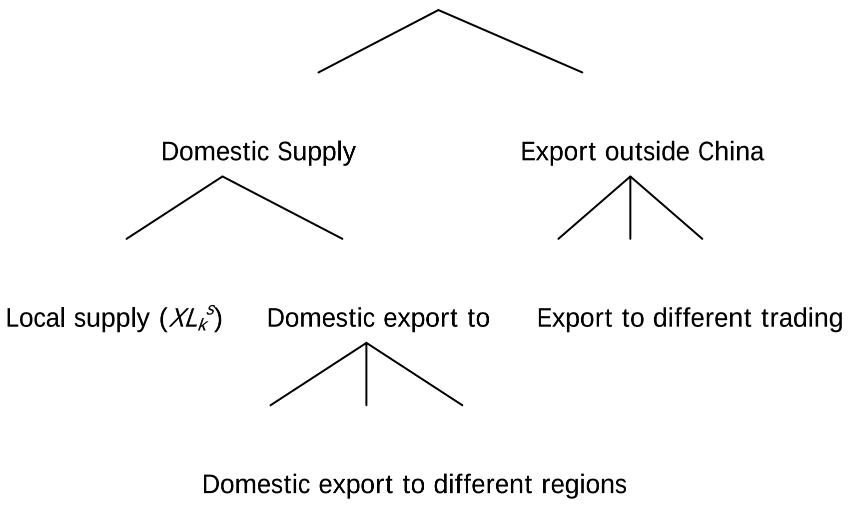



The top tier disaggregates the aggregate Armington demand into two components—demand for the aggregate domestically produced good and aggregate import demand. At the second tier, the aggregate import demand is allocated across trading partners. Meanwhile, the aggregate domestic demand is split into two parts—demand for locally produced goods and aggregate domestic import demand. At the third tier, the aggregate domestic import demand is allocated across different trading partners in the rest of main China. All of these tiers assume that goods indexed by *k* are differentiated by region of origin, i.e. the so-called Armington assumption. A CES specification is used to model the degree of substitutability across regions of origin.

The export supply is similarly modeled using a tiered constant-elasticity-of-transformation (CET) specification, see figure 4. This permits imperfect supply responses to changes in relative prices.

Finally, the small-country assumption is relaxed for exports with the incorporation of export demand functions.

**Figure 4 Export Structure**




### 2.10.1. Top-level Armington nest

Local demand for the Armington good, *XA*, is the sum of Armington demand over all local agents: intermediate demand, household and other local final demand, and demand generated by the internal trade and transport sector, *XAmg*, equation (T-1). Aggregate Armington demand is then allocated between domestic and import goods using a nested CES structure. Equation (T-2) represents demand for the domestically produced good, $XD^d$, where the top-level Armington elasticity is given by $\sigma^m$. Demand for aggregate imports, *XMT*, is determined in equation (T-3). The price of aggregate imports is given by *PMT*. The Armington price, *PA*, is defined in equation (T-4), using the familiar CES dual price aggregation formula.

$$XA_k = \sum_j XAp_{k,j} + \sum_h XAc_{k,h} + \sum_f XAf_{k,f} + \sum_m \sum_{k'} XAmg_{k,k',m} \qquad \text{T-1}$$

$$XD_k^d = \alpha_k^d \left( \frac{PA_k}{PD_k^d} \right)^{\sigma_k^m} XA_k \qquad \text{T-2}$$

$$XMT_k = \alpha_k^m \left( \frac{PA_k}{PMT_k} \right)^{\sigma_k^m} XA_k \qquad \text{T-3}$$

$$PA_k = \left[ \alpha_k^d PD_k^{d\ 1-\sigma_k^m} + \alpha_k^m PMT_k^{1-\sigma_k^m} \right]^{1/(1-\sigma_k^m)} \qquad \text{T-4}$$

### 2.10.2. Second-level Armington nest

At the second level, aggregate import demand, *XMT*, is allocated across trading partners using a CES specification. Equation (T-5) defines the domestic price of imports, *PM*. It is equal to the world price (in international currency), *WPM*, multiplied by the exchange rate, and adjusted for the import tariff, $\tau^m$, i.e. *PM* represents the port-price of imports, tariff-inclusive. Equation (T-6) represents the import of commodity *k* from region *r*, *XM*, where the inter-regional substitution elasticity is given by $\sigma^w$. The relevant consumer price includes the internal trade and transport margin, $\tau^{mg}$. The aggregate price of imports, *PMT*, is defined in equation (T-7).

On the other hand, the local demand for domestic goods, $XD_k^d$, is disaggregated into demand for local products, $XL_k^d$, and demand for total domestic imports, $XDMT_k$. The CES nest structure and the equation forms are the same as those of the top-level. Equations (Ta-1) to (Ta-3) define the variables above.

$$PM_{k,r} = ER.WPM_{k,r}(1+\tau^{m}_{k,r}) \qquad \text{T-5}$$

$$XM_{k,r} = \alpha^{w}_{k,r}\left(\frac{PMT_k}{(1+\tau^{mg}_{k,M})\,PM_{k,r}}\right)^{\sigma^{w}_{k}} XMT_k \qquad \text{T-6}$$

$$PMT_k = \left[\sum_r \alpha^{w}_{k,r}\left((1+\tau^{mg}_{k,M})\,PM_{k,r}\right)^{1-\sigma^{w}_{k}}\right]^{1/(1-\sigma^{w}_{k})} \qquad \text{T-7}$$

$$XL^{d}_{k} = \alpha^{dl}_{k}\left(\frac{PD^{d}_{k}}{\left(1+\tau^{mg}_{k,D}\right)PL_k}\right)^{\sigma^{dm}_{k}} XD^{d}_{k} \qquad \text{Ta-1}$$

$$XDMT_k = \alpha^{dmt}_{k}\left(\frac{PD^{d}_{k}}{PDMT_k}\right)^{\sigma^{dm}_{k}} XD^{d}_{k} \qquad \text{Ta-2}$$

$$PD^{d}_{k} = \left[\alpha^{dl}_{k}\left[\left(1+\tau^{mg}_{k,D}\right)PL_k\right]^{1-\sigma^{m}_{k}} + \alpha^{dmt}_{k}\,PDMT_k^{1-\sigma^{dm}_{k}}\right]^{1/(1-\sigma^{dm}_{k})} \qquad \text{Ta-3}$$

#### 2.10.3. Third-level Armington nest

At the third level, the aggregate domestic import demand, $XDMT_k$, is allocated across trading partners within China using a CES specification. Equation (Ta-4) represents the domestic import of commodity *k* from region *dr*, *XDM*, where the inter-regional substitution elasticity is given by $\sigma^{dw}$. The aggregate price of domestic imports, $PDMT_k$, is defined in equation (Ta-5).

$$XDM_{k,dr} = \alpha_{k,dr}^{dw} \left( \frac{PDMT_k}{(1+\tau_{k,D}^{mg})\ PDM_{k,dr}} \right)^{\sigma_k^{dw}} XDMT_k \qquad \text{Ta-4}$$

$$PDMT_k = \left[ \sum_{dr} \alpha_{k,dr}^{dw} \left( (1+\tau_{k,D}^{mg})\ PDM_{k,dr} \right)^{1-\sigma_k^{dw}} \right]^{1/(1-\sigma_k^{dw})} \qquad \text{Ta-5}$$

#### 2.10.4. Top-level CET nest

Domestic production is allocated across markets using a nested CET specification. At the top nest, producers allocate production between the domestic market and aggregate exports. At the second nest, aggregate exports are allocated across trading partners. Meanwhile, aggregate domestic exports are allocated across different regions within China. The model allows for perfect transformation, i.e. producers perceive no difference across markets. In this case, the law-of-one-price holds. Equation (T-8) represents the link between the domestic producer price, *PE*, and the world price, *WPE*. Export prices are both sector and region-specific. The FOB price, *WPE*, includes domestic trade and transport margins, $\tau^{mg}$, as well as export taxes and subsidies, $\tau^{e}$. Equations (T-9) and (T-10) represent the CET optimality conditions. The first determines the share of domestic supply, *X*, allocated to the domestic market, $XD^{s}$. The second determines the supply of aggregate exports, *XET*. *PET* represents the price of aggregate export supply. The transformation elasticity is given by $\sigma^{x}$. The model allows for perfect transformation. In this case, the optimal supply conditions are replaced by the law-of-one price conditions.
Equation (T-11) represents the CET aggregation function. In the case of finite transformation, it is replaced with its equivalent, the CET dual price aggregation function. In the case of infinite transformation, the primal aggregation function is used, where the two components are summed together since there is no product differentiation.

$$PE_{k,r}\left(1+\tau_{k,X}^{mg}\right)\left(1+\tau_{k,r}^{e}\right)=ER.WPE_{k,r} \quad \text{T-8}$$

$$\begin{cases} XD_k^s=\gamma_k^d\left(\dfrac{PD_k^s}{P_k}\right)^{\sigma_k^x}X_k & \text{if} \quad \sigma_k^x\neq\infty \\ PD_k^s=P_k & \text{if} \quad \sigma_k^x=\infty \end{cases} \quad \text{T-9}$$

$$\begin{cases} XET_k=\gamma_k^e\left(\dfrac{PET_k}{P_k}\right)^{\sigma_k^x}X_k & \text{if} \quad \sigma_k^x\neq\infty \\ PET_k=P_k & \text{if} \quad \sigma_k^x=\infty \end{cases} \quad \text{T-10}$$

$$\begin{cases} P_k=\left[\gamma_k^d PD_k^{s1+\sigma_k^x}+\gamma_k^e PET_k^{1+\sigma_k^x}\right]^{1/(1+\sigma_k^x)} & \text{if} \quad \sigma_k^x\neq\infty \\ X_k=XD_k^s+XET_k & \text{if} \quad \sigma_k^x=\infty \end{cases} \quad \text{T-11}$$

### 2.10.5. Second-level CET nest

The second-level CET nest allocates aggregate export supply, *XET*, across the various export markets, *XE*. Equation (T-12) represents the optimal allocation decision, where $\sigma^z$ is the transformation elasticity. Equation (T-13) represents the CET aggregation function, where again, the CET dual price formula is used to determine the aggregate export price, *PET*. As above, the model allows the transformation elasticity to be infinite. The second-level CET nest also distributes aggregate domestic supply between local market and domestic export markets of other regions within China. The structure of CET nest is just the same as that of top-level. And equations (Ta-6) to (Ta-10) define the relevant variables.

$$\begin{cases} XE_{k,r} = \gamma_{k,r}^{x}\left(\dfrac{PE_{k,r}}{PET_k}\right)^{\sigma_k^z} XET_k & \text{if} \quad \sigma_k^z \neq \infty \\ PE_{k,r} = PET_k & \text{if} \quad \sigma_k^z = \infty \end{cases} \qquad \text{T-12}$$

$$\begin{cases} PET_k = \left[\sum_r \gamma_{k,r}^{x} PE_{k,r}^{1+\sigma_k^z}\right]^{1/(1+\sigma_k^z)} & \text{if} \quad \sigma_k^z \neq \infty \\ XET_k = \sum_r XE_{k,r} & \text{if} \quad \sigma_k^z = \infty \end{cases} \qquad \text{T-13}$$

$$\begin{cases} XL_k^s = \gamma_k^{sl}\left(\dfrac{PL_k}{PD_k^s}\right)^{\sigma_k^{sx}} XD_k^s & \text{if} \quad \sigma_k^{sx} \neq \infty \\ PD_k^s = PL_k & \text{if} \quad \sigma_k^{sx} = \infty \end{cases} \qquad \text{Ta-6}$$

$$\begin{cases} XSET_k = \gamma_k^{set}\left(\dfrac{PET_k^s}{PD_k^s}\right)^{\sigma_k^{sx}} XD_k^s & \text{if} \quad \sigma_k^{sx} \neq \infty \\ PD_k^s = PET_k^s & \text{if} \quad \sigma_k^{sx} = \infty \end{cases} \qquad \text{Ta-7}$$

$$\begin{cases} PD_k^s = \left[\gamma_k^{sl} PL_k^{1+\sigma_k^{sx}} + \gamma_k^{set} PET_k^{s1+\sigma_k^{sx}}\right]^{1/(1+\sigma_k^{sx})} & \text{if} \quad \sigma_k^{sx} \neq \infty \\ XD_k^s = XL_k^s + XSET_k & \text{if} \quad \sigma_k^{sx} = \infty \end{cases} \qquad \text{Ta-8}$$

### 2.10.6. Third-level CET nest

The third-level CET nest allocates aggregate domestic export supply, *XSET*, across the various markets in the rest of mainland China, $XE^s$. Equation (Ta-9) represents the optimal allocation decision, where $\sigma^{sz}$ is the transformation elasticity. Equation (Ta-10) represents the CET aggregation function, where again, the CET dual price formula is used to determine the aggregate domestic export price, $PET^s$. Also, the model allows for the infinite transformation elasticity.

$$\begin{cases} XE^{s}_{k,dr} = \gamma^{sz}_{k,dr} \left( \frac{PE^{s}_{k,dr}}{PET^{s}_{k}} \right)^{\sigma^{sz}_{k}} XSET_{k} & \text{if} \quad \sigma^{sz}_{k} \neq \infty \\ PE^{s}_{k,dr} = PET^{s}_{k} & \text{if} \quad \sigma^{sz}_{k} = \infty \end{cases} \qquad \text{Ta-9}$$

$$\begin{cases} PET^{s}_{k} = \left[ \sum_{dr} \gamma^{sz}_{k,dr} PE^{s\ \ 1+\sigma^{sz}_{k}}_{k,dr} \right]^{1/(1+\sigma^{sz}_{k})} & \text{if} \quad \sigma^{sz}_{k} \neq \infty \\ XSET_{k} = \sum_{dr} XE^{s}_{k,dr} & \text{if} \quad \sigma^{sz}_{k} = \infty \end{cases} \qquad \text{Ta-10}$$

## 2.11. Export Demand and Import Supply

Export demand of international market, *ED*, is specified by using a constant elasticity function, as shown by equation (T-14). If the elasticity, $\eta^{e}$, is finite, demand decreases as the international price of exports, *WPE*, increases. The numerator contains an exogenous export price competitive index. If the latter increases relative to the domestic export price, market share of the domestic exporter would increase. The model allows for infinite demand elasticity. This represents the small-country assumption. In this case, the domestic price of exports (in international currency units) is constant. If the two CET elasticities are likewise infinite, then the domestic producer price is also equal to the world price of exports (adjusted for taxes and trade and transportation margins).

We assume that the demand of domestic market, *DED*, takes the same functional form as that of international market. See equation (Ta-11). The small-country assumption is also taken into consideration.

We also use a constant elasticity function, equation (Ta-12), to describe the import supply of domestic market, *XSM*. If the elasticity, $\eta^{dm}$, is finite, supply increases as the price of domestic imports, *PDM*, increases. The denominator contains an exogenous domestic export price competitive index. If the latter increases relative to the domestic import price, market share of the domestic importer would decrease. The model allows for infinite demand elasticity, which means the imports from different regions in rest of mainland China are all the same and the domestic import price is constant.

$$\begin{cases} ED_{k,r} = \alpha^{e}_{k,r}\left(\dfrac{\overline{WPE}_{k,r}}{WPE_{k,r}}\right)^{\eta^{e}_{k,r}} & \text{if} \quad \eta^{e}_{k,r} \neq \infty \\ WPE_{k,r} = \overline{WPE}_{k,r} & \text{if} \quad \eta^{e}_{k,r} = \infty \end{cases} \qquad \text{T-14}$$

$$\begin{cases} ED^{d}_{k,dr} = \alpha^{de}_{k,dr}\left(\dfrac{\overline{DPE}_{k,dr}.PLEV}{PE^{s}_{k,dr}}\right)^{\eta^{de}_{k,dr}} & \text{if} \quad \eta^{de}_{k,dr} \neq \infty \\ PE^{s}_{k,dr} = \overline{DPE}_{k,dr}.PLEV & \text{if} \quad \eta^{de}_{k,dr} = \infty \end{cases} \qquad \text{Ta-11}$$

$$\begin{cases} XM^{s}_{k,dr} = \alpha^{dm}_{k,dr}\left(\dfrac{PDM_{k,dr}}{\overline{DPM}_{k,dr}.PLEV}\right)^{\eta^{dm}_{k,dr}} & \text{if} \quad \eta^{dm}_{k,dr} \neq \infty \\ PDM_{k,dr} = \overline{DPM}_{k,dr}.PLEV & \text{if} \quad \eta^{dm}_{k,dr} = \infty \end{cases} \qquad \text{Ta-12}$$

## 2.12. Domestic trade and transportation margins[6]

[6] We retained the equations in the regional model, although the trade and transportation margins are not captured in detail in the base SAM.

The marketing of each good—domestic, imports, and exports—is associated with a commodity specific trade margin. Equations (M-1) through (M-3) define the revenues associated with the domestic trade and transport margins. Equation (M-4) defines the volume of margin services. The production of the trade and transport services follows a Leontief technology.
Equation (M-5) defines the demand for goods and services. Equation (M-6) is the expenditure deflator for individual trade margin activities.

$$YT_{k,D}^{mg} = \tau_{k,D}^{mg} PD_k XD_k^d \qquad \text{M-1}$$

$$YT_{k,M}^{mg} = \sum_r \tau_{k,M}^{mg} PM_{k,r} XM_{k,r} \qquad \text{M-2}$$

$$YT_{k,X}^{mg} = \sum_r \tau_{k,X}^{mg} PE_{k,r} XE_{k,r} \qquad \text{M-3}$$

$$XT_{k,m}^{mg} = YT_{k,m}^{mg} / PT_{k,m}^{mg} \qquad \text{M-4}$$

$$XAmg_{k,k',m} = \alpha_{k,k',m}^{mg} XT_{k',m}^{mg} \qquad \text{M-5}$$

$$PT_{k',m}^{mg} = \sum_k \alpha_{k,k',m}^{mg} PA_k \qquad \text{M-6}$$

## 2.13. Goods market equilibrium

There are five fundamental commodities in the model—local goods sold locally, international and domestic imports (by region of origin), and international and domestic exports (by region of destination). All other goods are bundles (i.e. are defined using an aggregation function) and do not require a supply and demand balance. The small-country assumption holds for international imports, and therefore any import demand can be met by the rest of the world with no impact on the price of imports. Therefore, there is no explicit supply/demand equation for international imports. Equation (E-1) represents equilibrium on the local goods market, and essentially determines, *PL*, the producer price of the local good. Equation (E-2) defines the equilibrium condition on the international export market. With finite export demand elasticity, the equation determines *WPE*, the world price of exports. With infinite export demand elasticity, the equation trivially equates export demand to the given export supply. Equations (Ea-1) and (Ea-2) respectively define the equilibrium conditions on the domestic export and import markets.

$$XL_k^d = XL_k^s \qquad \text{E-1}$$

$$ED_{k,r} = XE_{k,r} \qquad \text{E-2}$$

$$ED_{k,dr}^d = XE_{k,dr}^s \qquad \text{Ea-1}$$

$$XDM_{k,dr} = XM_{k,dr}^s \qquad \text{Ea-2}$$

### 2.14. Macro closure

Macro closure involves determining the exogenous macro elements of the model. The standard closure rules of the model are the following:

- Government fiscal balance is exogenous, achieved with endogenous government savings.
- Private investment is endogenous and is driven by available savings.

- The volume of government current and investment expenditures is exogenous.
- The volume of demand for international trade and transport services is exogenous.
- The volume of stock changes is exogenous.
- The trade balance (i.e. capital flows) is exogenous. The real exchange rate equilibrates the balance of payments.

## 2.15. Government accounts

Equation (C-1) defines nominal tariff revenues, *TarY*, and equation (C-2) defines real tariff revenues, *RTarY*. Equation (C-3) defines total central government revenues, *GY*, the components including revenues from the production tax, business tax, import tax, land, capital and wage tax, corporate taxes, and some transfers. Equation (Ca-1) defines the local government revenues, *LGY*, which has similar components with central government revenues. We assume that the sales taxes on intermediate demand, household demand and other final demand, and income taxes belong to local government. Equation (C-4) represents central government's current expenditures, *GEXP*. It is the sum of expenditures on goods and services, and some transfers. Local government's expenditure, *LGEXP*, has the same structure as that of the central government, which is shown by equation (Ca-2). Central and local government savings (on current operations), $S^g$ and $S^{lg}$, are defined in equation (C-5) and (Ca-3) respectively, as the difference between revenues and current expenditures. Real central and local government savings, *RSg* and *RSlg*, are defined in equation (C-6) and (Ca-4) respectively.

$$TarY = ER\sum_k \sum_r \chi^{tm} \tau^m_{k,r} WPM_{k,r} XM_{k,r} \qquad \text{C-1}$$

$$RTarY = TarY / PLEV \qquad \text{C-2}$$

$$GY = \sum_i \left( pptx_i^c + pbtx_i^c \right) PX_i XP_i + TarY + \sum_{lt} \sum_i \frac{\tau_{i,lt}^{ftc} PT_{i,lt} T_{i,lt}^d}{1 + \tau_{i,lt}^{ftc} + \tau_{i,lt}^{ftl}}$$

$$+ \sum_{kt} \sum_i \frac{\tau_{i,kt}^{fkc} R_{i,kt} K_{i,kt}^d}{1 + \tau_{i,kt}^{fkc} + \tau_{i,kt}^{fkl}} + \sum_l \sum_i \frac{\tau_{i,l}^{flc} W_{i,l} L_{i,l}^d}{1 + \tau_{i,l}^{flc} + \tau_{i,l}^{fll}} + \sum_i \frac{\tau_i^{frc} PR_i NR_i^d}{1 + \tau_i^{frc} + \tau_i^{frl}}$$ C-3

$$+ \sum_e \kappa_e^{ccg} CY_e + ER.TR_W^{CG} + PLEV.TR_{ROMC}^{CG} + PLEV.TR_{LG}^{CG}$$

$$LGY = \sum_i \left( pptx_i^l + pbtx_i^l \right) PX_i XP_i + \sum_{lt} \sum_i \frac{\tau_{i,lt}^{ftl} PT_{i,lt} T_{i,lt}^d}{1 + \tau_{i,lt}^{ftc} + \tau_{i,lt}^{ftl}}$$

$$+ \sum_{kt} \sum_i \frac{\tau_{i,kt}^{fkl} R_{i,kt} K_{i,kt}^d}{1 + \tau_{i,kt}^{fkc} + \tau_{i,kt}^{fkl}} + \sum_l \sum_i \frac{\tau_{i,l}^{fll} W_{i,l} L_{i,l}^d}{1 + \tau_{i,l}^{flc} + \tau_{i,l}^{fll}} + \sum_i \frac{\tau_i^{frl} PR_i NR_i^d}{1 + \tau_i^{frc} + \tau_i^{frl}}$$ Ca-1

$$+ \sum_k \sum_j \tau_{k,j}^{cp} PA_k XAp_{k,j} + \sum_k \sum_h \tau_{k,h}^{cc} PA_k XAc_{k,h} + \sum_k \sum_f \tau_{k,f}^{cf} PA_k XAf_{k,f}$$

$$+ \sum_e \kappa_e^{clg} CY_e + \lambda^h \sum_h \kappa_h^h YH_h + ER.TR_W^{LG} + PLEV.TR_{ROMC}^{LG} + PLEV.TR_{CG}^{LG}$$

$$GEXP = YF_{CG} + PLEV \sum_h TR_{cg,h}^h + ER.TR_{CG}^W + PLEV.TR_{CG}^{ROMC} + PLEV.TR_{CG}^{LG}$$ C-4

$$LGEXP = YF_{LG} + PLEV \sum_h TR_{lg,h}^h + ER.TR_{LG}^W + PLEV.TR_{LG}^{ROMC} + PLEV.TR_{LG}^{CG}$$ Ca-2

$$S^g = GY - GEXP$$ C-5

$$S^{lg} = LGY - LGEXP$$ Ca-3

$$RSg = S^g / PLEV$$ C-6

$$RSlg = S^{lg} / PLEV$$ Ca-4

## 2.16. Investment and macro closure

Equation (C-7) defines the investment savings balance, which determines the investment level. Equations (C-8) and (Ca-5) respectively defines the exogenous volumes of public current and investment expenditures of central and local government. Equations (Ca-6) through (Ca-8) are pertinent to the account of extra-budget system. Equation (C-11) defines the exogenous volume of stock changes. The aggregate price level, *PLEV*, is the average absorption (Armington) price, which is defined by equation (C-12). Equation (Ca-9) and (Ca-10) represents the balance of payments (in domestic currency terms) in international and domestic market respectively. The latter can be shown to be redundant, and is dropped from the model specification.

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$$YF_{capacc} + YF_{inventory} = \sum_{e} S_e^c + \sum_{h} S_h^h + S^g + S^{lg} + S^{nfp} + ER.S^f + PLEV.S^{ROMC} \qquad \text{C-7}$$

$$XF_{cengov} = \overline{XF}_{cengov} \qquad \text{C-8}$$

$$XF_{locgov} = \overline{XF}_{locgov} \qquad \text{Ca-5}$$

$$CT^{fee} = \sum_{i} \tau_i^{cfee} PX_i XP_i \qquad \text{Ca-6}$$

$$S^{nfp} = CT^{fee} - YF_{extrasystem} \qquad \text{Ca-7}$$

$$XF_{extrasystem} = \overline{XF}_{extrasystem} \qquad \text{Ca-8}$$

$$XF_{inventory} = \overline{XF}_{inventory} \qquad \text{C-11}$$

$$PLEV = \frac{\sum_k PA_k XA_{k,0}}{\sum_k PA_{k,0} XA_{k,0}} \quad \text{C-12}$$

$$\begin{aligned}&\sum_r \sum_k WPE_{k,r} XE_{k,r} ER + \sum_h TR^h_{W,h} ER + TR^{lg}_W ER + S^f ER \\ &= \sum_r \sum_k WPM_{k,r} XM_{k,r} ER + \sum_{kt} TR^W_{k,kt} + \sum_h TR^w_h + \sum_e TR^W_{c,e} + TR^W_{lg} ER\end{aligned} \quad \text{Ca-9}$$

$$\begin{aligned}BoP \;&=\; \sum_{dr}\sum_k PE^s_{k,dr} XE^s_{k,dr} + \sum_h TR^h_{ROMC,h} PLEV + TR^{LG}_{ROMC} PLEV + S^{ROMC} PLEV \\ &-\; \sum_{dr}\sum_k PDM_{k,dr} XDM_{k,dr} - \sum_{kt} TR^C_{k,kt} - \sum_e TR^C_{c,e} - \sum_h TR^C_{h,dr} - TR^{ROMC}_{LG} PLEV \\ &\equiv\; 0\end{aligned} \quad \text{Ca-10}$$

## 2.17.Factor market equilibrium

### 2.17.1. Labor markets

Labor markets are assumed to clear. Equation (F-1) describes the upward sloping labor supply curve, including the two polar cases of a vertical supply curve and a horizontal supply curve, i.e. an infinite elasticity, in which case the real wage is fixed. Equation (F-2) sets aggregate demand, by skill-level, equal to aggregate supply, $L^s$. This equation determines the equilibrium wage, $W^e$. Equation (F-3) equates sectoral wages to the equilibrium wage, and allows for a fixed sector-specific relative wage factor, $\phi^l_{i,l}$ .

$$\begin{cases} L_l^s = \alpha_l^{ls}\left(\dfrac{W_l^e}{PLEV}\right)^{\omega^l} & \text{if} \quad \omega^l \neq \infty \\ W_l^e = PLEV.W_{l,0}^e & \text{if} \quad \omega^l = \infty \end{cases} \tag{F-1}$$

$$L_l^s = \sum_i L_{i.l}^d \tag{F-2}$$

$$W_{i,l} = \phi_{i,l}^l W_l^e \tag{F-3}$$

### 2.17.2. Labor Market Segmentation

In the equations above, labor market is assumed to be integrated, i.e. there is full labor mobility across sectors with a single economy-wide equilibrating wage rate for each labor type. For China's reality, it is more meaningful to describe a dual labor market where there is imperfect labor mobility between two sectors of the economy—rural and urban sectors. In the case of China in this model, the rural sector will be identified with the agricultural sectors and the urban sector with all other sectors, although there is significant non-agricultural activity occurring in rural areas. The implementation of dual labor markets follows the standard Harris-Todaro specification where the decision to migrate is a function of the expected income in the urban sector relative to the expected income in the rural sector. The specification in this model deviates somewhat from Harris-Todaro. First, relative wages will be used as a proxy for relative incomes. Second, actual wages will determine migration rather than expected wages in the absence of unemployment. The basic migration equation has the form given in equation (L-1), where *MIGR* represents the level of migration from rural to urban sectors.

The variable *AWAGE* is the average wage in the respective sectors. Letting the index *g* represent the geographic index, the average wage formula is given by equation (L-2). Note that the average wage is calculated based on the net-of-tax wage rate which matters to the worker deciding to migrate or not. Labor market equilibrium conditions are now based on two separate labor markets rather than the integrated market of the standard model. Thus with segmented markets, equations (F-1) through (F-3) are dropped from the model and replaced by equations (L-3) and (L-4).

$$MIGR_l = \chi_l^m \left( \frac{AWAGE_{Urb,l}}{AWAGE_{Rur,l}} \right)^{\omega_l^m} \quad \text{L-1}$$

$$AWAGE_{g,l} = \frac{\sum_{i \in g} \left( \frac{W_{i,l}}{1 + \tau_{i,l}^{flc} + \tau_{i,l}^{fll}} \right) L_{i,l}^d}{\sum_{i \in g} L_{i,l}^d} \quad \text{L-2}$$

$$L_{g,l}^s = \sum_{i \in g} L_{i,l}^d \quad \text{L-3}$$

$$W_{i,l} = \phi_{i,l}^l W_{g,l}^e \quad \text{for} \quad i \in g \quad \text{L-4}$$

$$L_{Rur,l}^s = \left(1 + g_{Rur,l}^L\right) L_{Rur,l,-1}^s - MIGR_l \quad \text{L-5}$$

$$L_{Urb,l}^s = \left(1 + g_{Urb,l}^L\right) L_{Urb,l,-1}^s + MIGR_l \quad \text{L-6}$$

$$L_{Tot,l}^s = L_{Rur,l}^s + L_{Urb,l}^s \quad \text{L-7}$$

Equation (L-3) determines the equilibrium wage rate by sector—i.e. rural and urban. It sets the aggregate geographic labor supply equal to the demand for labor in the same geographic zone, i.e. it determines the variable $W^e$ which is now indexed by both geographic zone as well as labor type. Equation (L-4) is equivalent to (F-3), but the relative wages are evaluated with respect to the zone-specific equilibrium wage. The definition of labor supply is given by equations (L-5) and (L-6). It is assumed that labor supply net of migration is given in any given period. In the case of comparative static simulations, geographic labor supply is simply exogenous and set to its base level, $L_0$. In the case of dynamic simulations, labor supply in each zone grows at some exogenous rate, $g^L$, and migration is subtracted from this amount in the rural zone, as shown in equation (L-5), and is added to labor supply in the urban zone, see equation (L-6). Equation (L-7) determines the total economy-wide labor supply for each labor type.

## 2.18. Capital market

Equilibrium on the capital market allows for both limiting cases—perfect capital mobility and perfect capital immobility, or any intermediate case. Aggregate capital, $K^s$, is allocated across sectors and type according to a nested CET system. At the top-level, the aggregate investor allocates capital across types, according to relative rates of return. Equation (F-3) determines the optimal supply decision, where $TK^s$ is the supply of capital of type $kt$, with an average return of $PTK$. $PK$ is the aggregate rate-of-return to capital. If the supply elasticity is infinite, the law-of-one-price holds. Equation (F-4) represents the top-level aggregation function, replaced by the CET dual price function in the case of finite transformation elasticity. Perfect capital mobility is represented by setting $\omega^{kt}$ to infinity. Perfect immobility is modeled by setting the transformation elasticity to 0.

$$\begin{cases} TK_{kt}^{s} = \gamma_{kt}^{tks}\left(\dfrac{PTK_{kt}}{PK}\right)^{\omega^{kt}} K^{s} & \text{if} \quad \omega^{kt} \neq \infty \\ PTK_{kt} = PK & \text{if} \quad \omega^{kt} = \infty \end{cases} \qquad \text{F-4}$$

$$\begin{cases} PK = \left[\sum_{kt} \gamma_{kt}^{tks} PTK_{kt}^{1+\omega^{kt}}\right]^{1/(1+\omega^{kt})} & \text{if} \quad \omega^{kt} \neq \infty \\ K^{s} = \sum_{kt} TK_{kt}^{s} & \text{if} \quad \omega^{kt} = \infty \end{cases} \qquad \text{F-5}$$

At the second level, capital by type, $TK^s$, is allocated across sectors using another CET function. Equation (F-6) determines the optimal allocation of capital of type *kt* to sector *i*, $K^s$, where the transformation elasticity is $\omega^k$. Equation (F-7) represents the CET aggregation function. The equilibrium return to capital, *R*, is determined in equation (F-8) by equating capital supply to demand.

$$\begin{cases} K_{i,kt}^{s} = \gamma_{i,kt}^{k} \left( \dfrac{R_{i,kt}}{\left(1+\tau_{i,kt}^{fkc}+\tau_{i,kt}^{fkl}\right) PTK_{kt}} \right)^{\omega^k} TK_{kt}^{s} & \text{if} \quad \omega^k \neq \infty \\ R_{i,kt} = PTK_{kt} & \text{if} \quad \omega^k = \infty \end{cases} \qquad \text{F-6}$$

$$\begin{cases} PTK_{kt} = \left[ \sum_i \gamma_{i,kt}^{k} \left( \dfrac{R_{i,kt}}{1+\tau_{i,kt}^{fkc}+\tau_{i,kt}^{fkl}} \right)^{1+\omega^k} \right]^{1/(1+\omega^k)} & \text{if} \quad \omega^k \neq \infty \\ TK_{kt} = \sum_i K_{i,kt}^{s} & \text{if} \quad \omega^k = \infty \end{cases} \qquad \text{F-7}$$

$$K_{i,kt}^{s} = K_{i,kt}^{d} \qquad \text{F-8}$$

### 2.19. Land market

Land market equilibrium is specified in an analogous way to the capital market with a tiered CET supply system. The first tier allocates total land across types. This could have zero transformation elasticity if for example land used for rice production could not be used to produce other commodities. Their respective prices are *PLAND* and $PTT^s$.

$$\begin{cases} TT_{lt}^{s} = \gamma_{lt}^{tts}\left(\dfrac{PTT_{lt}^{s}}{PLAND}\right)^{\omega^{tl}} LAND & \text{if} \quad \omega^{tl} \neq \infty \\ PTT_{lt}^{s} = PLAND & \text{if} \quad \omega^{tl} = \infty \end{cases}$$ F-9

$$\begin{cases} PLAND = \left[\sum_{lt} \gamma_{lt}^{tts}\left(PTT_{lt}^{s}\right)^{1+\omega^{tl}}\right]^{1/(1+\omega^{tl})} & \text{if} \quad \omega^{tl} \neq \infty \\ LAND = \sum_{lt} TT_{lt}^{s} & \text{if} \quad \omega^{tl} = \infty \end{cases}$$ F-10

Equations (F-11) and (F-12) determine the optimality conditions at the second and final tier, determining land supply (by type and) by sector of use. Land market equilibrium is represented by equation (F-13).

$$\begin{cases} T_{i,lt}^{s} = \gamma_{i,lt}^{t}\left(\dfrac{PT_{i,lt}}{\left(1+\tau_{i,lt}^{ftc}+\tau_{i,lt}^{ftl}\right)PTT_{lt}^{s}}\right)^{\omega_{lt}^{t}} TT_{lt}^{s} & \text{if} \quad \omega_{lt}^{t} \neq \infty \\ PT_{i,lt} = PTT_{lt}^{s} & \text{if} \quad \omega_{lt}^{t} = \infty \end{cases}$$ F-11

$$\begin{cases} PTT_{lt}^{s} = \left[\sum_{i} \gamma_{i,lt}^{t}\left(\dfrac{PT_{i,lt}}{1+\tau_{i,lt}^{ftc}+\tau_{i,lt}^{ftl}}\right)^{1+\omega^{t}}\right]^{1/(1+\omega_{lt}^{t})} & \text{if} \quad \omega_{lt}^{t} \neq \infty \\ TT_{lt}^{s} = \sum_{i} T_{i,lt}^{s} & \text{if} \quad \omega_{lt}^{t} = \infty \end{cases}$$ F-12

$$T_{i,lt}^{s} = T_{i,lt}^{d}$$ F-13

### 2.19.1. Natural resource market

The market for natural resources differs from the others in the sense that, there is no inter-sectoral mobility, i.e. this is a sector specific resource. There is therefore a sector specific supply curve (eventually flat). Equation (F-14) describes the sector-specific supply function, or $NR^s$. Equation (F-15) then determines the equilibrium price, $PR$.

$$\begin{cases} NR_i^s = \gamma_i^{nr}\left(\dfrac{PR_i}{PLEV}\right)^{\omega^{nr}} & \text{if} \quad \omega^{nr} \neq \infty \\ PR_i = PLEV.PR_{i,0} & \text{if} \quad \omega^{nr} = \infty \end{cases} \qquad \text{F-14}$$

$$NR_i^d = NR_i^s \qquad \text{F-15}$$

## 2.20. Macroeconomic identities

Equations (I-1) and (I-2) define nominal and real GDP, respectively, at market prices. Equation (I-3) is the GDP at market price deflator. Similarly, equations (I-4) and (I-5) define nominal and real GDP at factor cost. Note that real GDP at factor cost is evaluated in efficiency units. Equation (I-6) defines the GDP at factor cost deflator.

$$\begin{aligned} GDPMP \quad = \quad & \sum_k \sum_h (1+\tau_{k,h}^{cc}) PA_k XAc_{k,h} + \sum_k \sum_f (1+\tau_{k,f}^{cf}) PA_k XAf_{k,f} \\ + \quad & ER \sum_k \sum_r WPE_{k,r} XE_{k,r} - ER \sum_k \sum_r WPM_{k,r} \ XM_{k,r} \\ + \quad & \sum_k \sum_{dr} PE_{k,dr}^s XE_{k,dr}^s - \sum_k \sum_{dr} PDM_{k,dr} \ XDM_{k,dr} \end{aligned} \qquad \text{I-1}$$

$$
\begin{aligned}
RGDPMP \quad = \quad & \sum_k \sum_h (1+\tau^{cc}_{k,c,0}) PA_{k,0} XAc_{k,h} + \sum_k \sum_f (1+\tau^{cf}_{k,f,0}) PA_{k,0} XAf_{k,f} \\
+ \quad & ER_0 \sum_k \sum_r WPE_{k,r,0} XE_{k,r} - ER_0 \sum_k \sum_r WPM_{k,r,0} \ XM_{k,r} \\
+ \quad & \sum_k \sum_{dr} PE^s_{k,dr,0} XE^s_{k,dr} - \sum_k \sum_{dr} PDM_{k,dr,0} \ XDM_{k,dr}
\end{aligned}
\qquad \text{I-2}
$$

$$
PGDPMP = GDPGMP / RGDPMP \qquad \text{I-3}
$$

$$
GDPFC = \sum_l \sum_i W_{i,l} L^d_{i,l} + \sum_{kt} \sum_i R_{i,kt} K^d_{i,kt} + \sum_{lt} \sum_i PT_{i,lt} T^d_{i,lt} + \sum_i PR_i NR^d_i \qquad \text{I-4}
$$

$$
\begin{aligned}
RGDPFC \quad = \quad & \sum_l \sum_i W_{i,l,0} \lambda^l_{i,l} L^d_{i,l} + \sum_{kt} \sum_i R_{i,kt,0} \lambda^k_{i,kt} K^d_{i,kt} \\
+ \quad & \sum_{lt} \sum_i PT_{i,lt,0} \lambda^t_{i,lt} T^d_{i,lt} + \sum_i PR_{i,0} \lambda^r_i NR^d_i
\end{aligned}
\qquad \text{I-5}
$$

$$
PGDPFC = GDPGFC / RGDPFC \qquad \text{I-6}
$$

## 2.21. Growth equations

In a simple dynamic framework, equation (G-1) defines the growth rate of GDP at market price. Equation (G-2) determines the growth rate of labor productivity. The growth rate has two components, a uniform factor applied in all sectors to all types of labor, $\gamma^l$ , and a sector- and skill-specific factor, $\chi^l_{ip,l}$ . In defining a baseline, the growth rate of GDP is exogenous. In this case, equation (G-1) is used to calibrate the $g^y$ parameter. In policy simulations, $g^y$ is given, and equation (G-1) defines the growth rate of GDP. Other elements of simple dynamics include exogenous growth of labor supply, exogenous growth rates of capital and land productivity (typically 0), and investment driven capital accumulation, etc.

$$RGDPMP = (1 + g^y)\ RGDPMP_{-1} \quad \text{G-1}$$

$$\lambda^l_{ip,l} = (1 + \gamma^l + \chi^l_{ip,l})\ \lambda^l_{ip,l,-1} \quad \text{G-2}$$

# 3. Annex: Model Variables and Parameters List

Tables 2-5 provide a complete list of model variables and parameters. Table 2 and table 3 list respectively endogenous and exogenous model variables. Table 4 provides a list of key model parameters, mostly substitution elasticity. Table 5 provides a list of the model's calibrated share parameters. Each table has three columns. The first column represents the symbol of the respective variables or parameters as used in this document. The second column shows the equivalent GAMS names with the appropriate indices. The third column provides a brief description.

**Table 2 Endogenous Variables**

## Table 3 Exogenous Variables

## Table 4 Key Model Elasticity

## Table 5 Calibrated parameters