Further Opening of Japan's Agriculture Sector: An Applied General Equilibrium Analysis of Possible Impact

Hidetaka Kawano

The objective of this paper is to measure the impact of further opening of the agriculture sector on wages and employment in Japan; a two-sector applied general equilibrium model is used as a framework. For the empirical model construction, calibration is achieved through the use of year 2000 Japan input-output data. The major simulation results of a balanced budget and import expansion of the agriculture sector lead to the following conclusion: Japan, with any further opening of her agriculture sector, will have an increasingly higher wage rate as both agriculture and non-agriculture sectors become increasingly more capital intensive with a portion of scarce labor relocating from the shrinking capital-intensive agriculture to the expanding labor-intensive non-agriculture sector. The agriculture sector, which contrary to common belief turns out to be highly capital-intensive, is seriously harmed by import expansion, even though the total welfare for the nation is increased. A portion of the total welfare gain of 3.32 trillion yen (US$ 30 billion) a year can be used to institute a constructive policy scheme to help those workers who need help for new work during the transition period. However, the agriculture sector needs to be exposed to international competition if it is to be prosperous and Japan is to be a major player in the international market place.

JEL classification: C63; C68; D00; D58; F10; F11; F16; Q11; Q12; Q17; Q18
Keywords: Applied general equilibrium; Trade; Factor intensities; Factor prices; Product prices; Welfare

1 Introduction

Japan has derived substantial benefits from engaging in international trade over many decades. Further increased open trade will be one of the important factors for raising average living standards of people in the country. However, agricultural trade liberalization has remained controversial and should be debated empirically and practically.

The huge costs of agricultural protection were reported by the the Organization for Economic Cooperation and Development (OECD) [10, 1998]; Producer subsidy equivalent (PSE), a measure of the value of total support to agricultural producers as a percent of the value of agricultural production, averaged 35 percent of the value of production in the OECD countries in 1997; In the recent OECD estimates [11, 2007], for all OECD countries, the PSE averaged 28 percent in 2005 and 23 percent in 2007. For Japan, the PSE was 54 percent in 2005 and 45 percent in 20077. The benefits of agricultural liberalization were also discussed in a recent book by Southgate, Graham, and Tweeten [14, 2007: 124-42]. Japan

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is no exception in its resistance to ongoing agricultural liberalization.

The objective of this paper is to measure the impact of further opening of the agriculture sector on wages and employment in Japan; a two-sector applied general equilibrium model is used as a framework. Expansion of trade volume can be theoretically explained by many possible causes, as in Deardorff and Hakura [3, 1994: 84-90]. In this paper, the impact of further opening of the agriculture sector on wages, employment, and the total welfare changes is measured. The model was kept simple to best match the task at hand.

For the empirical model construction, calibration is achieved in this model through the use of year 2000 Japanese economies 32-sector input-output data [9, 2004]. The data is grouped into two sectors. One is the agriculture sector classified as code 001 in the data, defined as industry 0. The other is a highly aggregated non-agriculture sector, defined as industry 1. Also incorporated is Leontief type input-output accounting data. The model closure is a small open economy with free capital inflow and outflow, so that the balance of payments is balanced. In this way, the original input-output data was used without modification.

A crucial step in the empirical characterization of an applied general equilibrium model (AGE) is calibration, defined as "the requirement that the entire model specification be capable of generating a base-year equilibrium observation as a model solution" (Shoven and Whalley [13, 1992:103]). An AGE model is a very powerful framework for analysis of policy reforms that could be instituted for Pareto improvements in the current state of the economy. An important development since Scarf [12, 1967] has been the use of observed data, such as that in an input-output table, in developing an AGE model.

The solution procedure for coding the model follows Shoven and Whalley [13, 1992: 43- 4] by reducing the dimensionality of the solution space to the number of factors of production in this general equilibrium structure. The solution algorithm used for calibration is a fixed-point algorithm originally developed by Kimbell and Harrison [7, 1986] and modified by Kawano [5, 2003]. In my recent paper [6, 2006], four alternative fixed point algorithms were compared. Among the four alternatives, the modified Kimbell-Harrison approach was shown to be the best for an AGE modeling.

The major simulation results of a balanced budget, 244% import expansion of the agriculture sector are the following: (1) the total national income is increased by 0.28% (the CV and EV measures of the welfare increase are 3.32 trillion yen and 3.33 trillion yen, respectively); (2) both wage and capital income in the agriculture sector are decreased by 44.70%; (3) employment in the agriculture sector is decreased by 44.70%; (4) the Stolper-Samuelson effect, which deals precisely with the effects of trade on wages and other factor prices, is demonstrated, since real return to labor \( w/p_0 \) and \( w/p_1 \) increase by 0.60% and 0.37%. In addition, real return to capital \( r/p_0 \) and \( r/p_1 \) decrease by 0.18% and 0.41%, respectively. Meanwhile the relative price of capital-intensive agricultural commodity \( p_0/p_1 \) decreases by 0.24%, (5) Further trade opening of a balanced budget 278% import and 10% export expansion enhanced the results of the earlier simulation. In brief, the simulation results of a balanced budget and import expansion of the agriculture sector lead to the following conclusion: Japan, with any further opening of her agriculture sector, will have an increasingly higher wage rate as both
agriculture and non-agriculture sectors become increasingly more capital intensive with a portion of scarce labor relocating from the shrinking capital-intensive agriculture to the expanding labor-intensive nonagriculture sector. The agriculture sector, which contrary to common belief turns out to be highly capital-intensive, is seriously harmed by import expansion, even though the total welfare for the nation is increased. A portion of the total welfare gain of 3.32 trillion yen can be used to institute a constructive policy scheme to alleviate the hardship for workers in the agriculture sector during the transition period. However, Japan's agriculture sector needs to be exposed to international competition if the sector is to be prosperous and to be a major player in the international market place.

For the replication check, the calibrated parameters are capable of generating a baseyear equilibrium observation as a model solution. This data can therefore be considered as an appropriate benchmark for various comparative static experiments. Calibration results must show that the unit-price convention is kept in both goods and factor markets.

This experiment was conducted using Intel's 333MHz Pentium II processor and was programmed in C-language. The verified reliability of the simulation results in double precision (1.0e - 15). The converged equilibrium values in this benchmark model were obtained through 47 iterations over the entire model.

In section 2, the empirical structure of the model is specified. In section 3, the calibration procedure is described. In section 4, the major simulation results are presented. The conclusion follows in section 5. All notations are defined as they appear for the first time in the text. In Appendix A, there is a list of

Figure 1: An Overview of Commodity and Service Flows of Japanese Economy in 2000 (Yen Trillion)
the definitions of variables. The entire model structure is presented in Appendix B.

2 The Empirical General Structure of the Model

2.1 The Main Features of the Model

The model was kept very simple. For example, I assumed that both domestic and international prices moved together and that both were the same for the simplicity of the model. The supply side of a theoretical general equilibrium model is made more empirically plausible by incorporating the Leontief type input-output accounting data. An important step in building an empirical model is to incorporate flow of intermediate goods into the model structure. The flow of intermediate goods among different sectors is built into the

Figure 2: An Illustrative General Equilibrium Model Incorporating Intermediate Goods
model as part of production activity in the economy, as shown in Figure 1. The overview of the benchmark model is presented in Figure 2.

The model is simple and has only two sectors, shown by subscript \( i \in I = \{0, 1\} \), and two final consumption commodities \( X_{i \in I} \). The use of intermediate goods in production activities shows that total output \( Q_{i \in I} \) in sector \( i \) will go partly to meet domestic household consumption demand \( X_{i \in I} \), external sector consumption \( ES_{i \in I} \), and also intermediate input demand \( q_{ij} \) for production of goods \( j \in J = \{0, 1\} \). The production activities of firms include intermediate goods \( Q_{j \in J} \) supplied through output markets. The usual primary factors of production are capital \( K_{i \in I} \) and labor \( L_{i \in I} \). As in the Leontief system, intermediate inputs are required as a fixed proportion of the total output \( Q_{j \in J} \). All relevant input-output information is summarized in Table 1. The input-output coefficients \( a_{ij} \) are defined as:

\[
a_{ij} = \frac{q_{ij}}{Q_j}, \quad \forall \quad i \in I, \ j \in J,
\]

where

\[
a_{ij} := \text{input-output coefficient for commodity } i \text{ used as an intermediate good to produce one unit of commodity } j
\]

\[
q_{ij} := \text{amount of good } i \text{ used as an intermediate input for production of good } j,
\]

\[
Q_j := \text{output in industry } j.
\]

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<tr>
<th>Table 1. Input-Output Accounting Table Flows</th>
<th>(Yen Trillion)</th>
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<td>Input to industry 1</td>
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<tr>
<td>Labor</td>
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</table>

Note: Capital is broadly defined as gross value added without labor income.

The input-output table can be looked at in both rows and columns. Here, the table is interpreted in rows.

In row 1 in the table, the value of the domestic production in the agriculture sector is 7.58 trillion yen. Sales value of 0.17 trillion yen goes to its own sector, the other 5.66 trillion yen to non-agriculture sector, 3.13 trillion yen for domestic consumption, and the remaining 1.37 trillion yen worth of net import from external sector.

In row 2, the value of the domestic production in a non-agriculture sector is 951.30 trillion yen. Sales value of 2.54 trillion yen goes to the agriculture sector, the other 431.04 trillion yen to its own non agriculture sector, 513.03 trillion yen for domestic consumption, and the remaining 4.70 trillion yen worth of net export to external sector.

In row 3, the total endowment of capital is 243.89 trillion yen, of which 4.53 trillion yen worth of capital is used in the agriculture sector and 239.36 trillion yen worth of capital is used in the non-agriculture sector.
In row 4, the total endowment of labor is 275.59 trillion yen, of which 0.34 trillion yen worth of labor is employed in the agriculture sector and 275.25 trillion yen worth of labor is employed in the non-agriculture sector.

2.2 The Demand Side of the Model

The level of disposable income for a representative consumer is determined by factor endowments, factor prices, and external finance. The disposable income $Y$ is:

$$ Y = wL + rK + EF, $$

where

- $w$ := wage rate,
- $r$ := rental rate,
- $L$ := labor endowment,
- $K$ := capital endowment,
- $EF$ := external finance.

We assume a simple Cobb-Douglas utility function $U(.)$ as a representation of consumer preference. The function is:

$$ U(X_0, X_i) = \prod_{i=0}^{I} x_i^{\theta_i}, \quad : \quad 0 < \theta_i < 1, \quad \sum_{i=0}^{I} \theta_i = 1, \quad \forall i \in I. $$

The final demand for commodities $X_{i \in I}$ is derived by the utility maximization for a representative consumer as:

$$ X_i = \frac{\theta_i Y}{p_i}, \quad \forall i \in I, $$

where

- $\theta_{i \in I}$ := share parameter in utility function,
- $p_i$ := price of commodity.

2.3 The Production Side of the Model

The production function with intermediate inputs is modeled as:

$$ Q_j = \min \left( \frac{q_{0j}}{a_{0j}}, \frac{q_{ij}}{a_{ij}}, VA_j \right), \quad \forall j \in J, $$

where

- $Q_j$ := commodity $j \in J$ produced,
- $VA_i$ := value-added component of production function $j \in J$.

The value-added component $VA_{j \in J}$ of production function $j \in J$ is modeled as Cobb-Douglas which allows the substitution possibility between primary factors: capital $k_i$ and $L_j$. The value-added component $VA_j$ is specified as:

$$ VA_i = \Phi_i K_i^{\alpha_i} L_i^{1-\alpha_i}, \quad : \quad 0 < \alpha_i < 1, \quad \forall i \in I, $$

where

- $\alpha_{i \in I}$ := factor share parameter in value-added component of production function,
- $\Phi_{i \in I}$ := shift parameter in value-added component of production function,
- $K_{i \in I}$ := capital employed in sector $i \in I$,
- $L_{i \in I}$ := labor employed in sector $i \in I$.

The conditional factor demand functions can be derived by assuming no intermediate goods are needed in the model, since a fixed proportion of the total output $Q_i$ does not affect the first order conditions of the producers’ cost minimization.

1) The per unit capital demand function is:

$$ k_i = \frac{1}{\Phi_i} \left( \frac{\alpha_i}{1-\alpha_i} \right)^{1-\alpha_i} \left( \frac{w}{r} \right)^{1-\alpha_i}, \quad \forall i \in I. $$

2) The per unit labor demand function is:

$$ l_i = \frac{1}{\Phi_i} \left( \frac{\alpha_i}{1-\alpha_i} \right)^{-\alpha_i} \left( \frac{w}{r} \right)^{-\alpha_i}, \quad \forall i \in I. $$
2.4 Zero Profit Conditions

Perfectly competitive behavior in producers will imply zero profit conditions. Zero profit conditions for the two producers with intermediate goods are modeled as: For the producer in sector \( i \in I \),

\[ p_i = \sum_{j \in J} a_{ij} p_j + r k_i + w l_i, \quad \forall i \in I, \tag{9} \]

where

\( k_i := \) capital employed for per unit production of commodity \( i \in I \),
\( l_i := \) labor employed for per unit production of commodity \( i \in I \).

Rewrite equations (9) in matrix as:

\[ (I - A^T)P = W. \tag{10} \]

Solve for \( P \) as:

\[ P = (I - A^T)^{-1}W. \tag{11} \]

2.5 Market Clearing Conditions

The total output \( Q_{i \in I} \) of commodity in sector \( i \in I \) is met by the total intermediate input demand \( \sum_{j \in J} q_{ij} \) domestic consumption demand \( X_{i \in I} \), and external consumption demand \( ES_{i \in I} \) as:

\[ Q_i = \sum_{j \in J} q_{ij} + X_i + ES_i, \quad \forall i \in I. \tag{12} \]

By equation (1), \( q_{ij} = a_{ij} Q_j \). Rewrite equation (12) as:

\[ Q_i = \sum_{j \in J} a_{ij} Q_j + X_i + ES_i, \quad \forall i \in I. \tag{13} \]

Further rewrite equation (13) in matrix as:

\[ (I - A)Q = X + ES. \tag{14} \]

Solve for \( Q \) as:

\[ Q = (I - A)^{-1}(X + ES). \tag{15} \]

Appendix B shows the entire structure of the general equilibrium model incorporating intermediate goods in production.

3 Calibration Procedure

Here, I calibrated the general equilibrium model to be consistent with an actual data set. In other words, choose the model parameters to replicate the real data at hand. The calibration procedure is as follows:

**Step 1:** Read information from the year 2000 Japanese Economy 32-sector input-output data file, and aggregated the sectoral data to create the 2 sector input-output data file; one file is the aggregated agriculture sector, and other is all the rest of the sectors aggregated. The program uses the data to calibrate parameters. The calibrated parameters are: 1) consumption-share parameters \( \theta_{i \in I} \), 2) factor-share parameters \( a_{i \in I, j} \), 3) intermediate input coefficients \( a_{i \in I, j \in J} \), and 4) shift parameters in production \( \Phi_{i \in I} \). These parameters are computed in double precision.

**Step 2:** Generate a micro-consistent data set summarized in the social accounting matrix shown in Table 2. Its zero-sum row shows that all goods and factor markets are cleared. Its zero-sum column shows that income equals expenditure in each sector. The generated data set shows micro-consistent financial flows in all sectors of the economy. In other words, the data is consistent with the underlying general equilibrium structure of the model.

**Step 3:** Conduct the replication check to see if the calibrated solutions in the model are error-free in building and coding the model. The generated data is identical to the original input-output table data in Table 1. The replication check has passed, so the data is considered as an appropriate benchmark for comparative static experiments.
Table 2. Social Accounting Matrix for Japan in 2000. (Yen trillion)

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<tr>
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<th>Industry 1</th>
<th>Domestic consumption</th>
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Note: Income is shown as a positive entry, expenditures shown as a negative entry.

Figure 3: An Illustrative Output Market in the Benchmark Model for Japanese Economy in 2000 (Yen Trillion)
4 Simulation Results for Import Expansion

The benchmark model used in this simulation is illustrated in Figures 3 and 4. The model calibrated the Japanese input-output table for the year 2000. The computed values in prices of goods and factors are almost of unitary value computed in double precision, which indicates the calibrations of parameter values are consistent with the model structure. This consistency is also assured by the computed values of both column-sum and row-sum in the social accounting matrix in Table 2.

In Figure 3, the total domestic consumption and total factor income are each 516.156 trillion yen. Net import value in sector 0 is 1.370 trillion yen. Net export value in sector 1 is 4.69 trillion yen. The total net export (the current account surplus) is 3.326 trillion yen. Production in sector 0 is 7.582 units and in sector 1 it is 951.305 units. Consumption in sector 0 is 3.130 units and in sector 1 is 513.026 units (line 41-2). Total national income is 516.156 trillion yen. Total value of domestic production of good 0 is 7.582 trillion yen. Total value of domestic production of good 1 is 951.305 trillion yen.

Figure 4: An Illustrative Factor Market in the Benchmark Model for Japanese Economy in 2000 (Yen Trillion)
In Figure 4, demand for capital in sector 0 is 4.535 units and that in sector 1 is 239.358 units. Demand for labor in sector 0 is 0.342 units while demand in sector 1 is 275.247 units. The capital-labor ratio in sector 0 is 13.265, whereas the ratio for sector 1 is 0.870. The factor endowed capital-labor ratio is 0.885, which is in the cone of diversification. As a comparative statics exercise summarized in Table 3, the major simulation results of a balanced budget 244% import expansion of the agriculture sector are the following: (1) the total national income is increased by 0.28% (the CV and EV measures of the welfare increase are 3.32 trillion yen and 3.33 trillion yen, respectively); (2) both wage and capital income in the agriculture sector are decreased by 44.70%; (3) employment in the agriculture sector is decreased by 44.70%; (4) the Stolper-Samuelson effect, which deals

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</table>

Note: The two simulation results were compared with the benchmark values. In Simulation 1, a comparative statics exercise of a balanced budget, 244% import expansion of the agriculture sector was conducted. In Simulation 2, the exercise of further trade opening of a balanced budget, 278% import and 10% export expansion was conducted.
precisely with the effects of trade on wages and other factor prices, is demonstrated, since real return to labor $w/p_0$ and $w/p_1$ increase by 0.60% and 0.37%. In addition, real return to capital $r/p_0$ and $r/p_1$ decrease by 0.18% and 0.41%, respectively. Meanwhile the relative price of capital-intensive commodity $p_0/p_1$ decreases by 0.24%, (5) Further trade opening of a balanced budget, 278% import and 10% export expansion enhanced the results of the earlier simulation.

The simulation results imply that the more capital-intensive agriculture sector shrinks, the higher the factor payment to its sector's non-intensive factor of labor. In other words, the shrinking capital-intensive agriculture sector releases labor and capital. Then these factors are reemployed in the expanding labor-intensive non-agriculture sector over time. Labor becomes increasingly scarcer than capital does. As a result, the value of the marginal product of labor and the corresponding real wage rate tend to increase, which in turn increases the capital intensity of the labor-intensive non-agriculture sector. In the end, the overall economy-wide capital intensity tends to increase as labor-intensive nonagriculture sector expands while the capital-intensive

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Figure 5: Comparative Statics: Import Expansion of the Agriculture Sector in Japan to Achieve the Balanced Trade Account (Yen Trillion) (Note: The small boxed values show the increased values from the benchmark.)
agriculture sector becomes smaller. Therefore, both sectors become more capital-intensive, which also implies increasingly scarce labor and higher wage rate in the economy. These comparative statics results are illustrated in Figures 5 and 6, where the small-boxed values indicate the increased values from the benchmark results in Figures 3 and 4.

The actual Japan's production function and contract curve of the benchmark are shown in Figures 7 and 8.

Figure 6: Comparative Statics: Change in the Factor Market with Import Expansion of the Agriculture Sector in Japan to Achieve the Balanced Trade Account (Yen Trillion) (Note: The small boxed values show the increased values from the benchmark.)
Figure 7: Japan’s Contract Curve for the Benchmark: $\alpha_0 = 0.93$ and $\alpha_1 = 0.47$.

Figure 8: Japan’s Production Possibilities Frontiers for the Benchmark: $\alpha_0 = 0.93$ and $\alpha_1 = 0.47$. 
5 Conclusion

The simulation results lead to the following conclusion: Japan, with any further opening of her agriculture sector, will have an increasingly higher wage rate as both agriculture and non-agriculture sectors become increasingly more capital intensive with a portion of scarce labor relocating from the shrinking capital-intensive agriculture to the expanding labor-intensive non-agriculture sector.

The agriculture sector, which contrary to common belief turns out to be highly capital-intensive, is seriously harmed by import expansion, even though the total welfare for the nation is increased. A portion of the total welfare gain of 3.32 trillion yen (US$ 30 billion) a year can be used to institute a constructive policy scheme to help those workers who need help for new work during the transition period. However, the agriculture sector needs to be exposed to international competition if it is to be prosperous and Japan is to be a major player in the international market place.

(Received: December 15, 2008, Accepted: December 18, 2009)

Notes

1) Irwin [4, 1996] and Bhagwati [2, 2002] have debated over the economic merits of free trade. The negative effects of protectionism are well documented by Bhagwati [1, 1988]. Krugman [8, 1987:131-2] has stated: “...the case for free trade is currently more in doubt than at any time since the 1817 publication of Ricardo's Principles of Political Economy...” However, he also noted that “... free trade is not pass'ed.... Its status has shifted from optimum to reasonable rule of thumb. There is still a case for free trade as a good policy, and as a useful target in the practical world of politics, ...”

2) The costs of agricultural protection and some misconceptions about agricultural trade liberalization were discussed (see Tokarick [15, 2008: 199-216]).

3) Among the causes are tariff cut on imports, the foreign expansion of import-competing goods, technical progress in exporting goods at home, technical progress at home in import-competing goods, and rise in expenditure at home. The main message of their examples is that there are many possible reasons for the volume of trade increase, which a.ects the skill di.ential in domestic labor markets.

4) Both domestic and international prices converge as all import restrictions like tari.s and quotas are gradually removed to open up the agricultural trade.

5) This assures that the model converges.

References

# APPENDIX

## A Variable Definitions

<table>
<thead>
<tr>
<th>Variable</th>
<th>Code</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>$X_{ij}$</td>
<td>$X[i]$</td>
<td>Domestic consumption demand for commodity $i$,</td>
</tr>
<tr>
<td>$ES_i$</td>
<td>$ES[i]$</td>
<td>External sector demand for commodity $i$,</td>
</tr>
<tr>
<td>$EF$</td>
<td>EF</td>
<td>External finance,</td>
</tr>
<tr>
<td>$Q_i$</td>
<td>$Q[i]$</td>
<td>Commodity $i$ produced,</td>
</tr>
<tr>
<td>$L$</td>
<td>lbar</td>
<td>Labor endowment in the economy,</td>
</tr>
<tr>
<td>$K$</td>
<td>kbar</td>
<td>Capital endowment in the economy,</td>
</tr>
<tr>
<td>$L_i$</td>
<td>l[i]</td>
<td>Labor employed for production of commodity $i$,</td>
</tr>
<tr>
<td>$K_i$</td>
<td>k[i]</td>
<td>Capital employed for production of commodity $i$,</td>
</tr>
<tr>
<td>$l_i$</td>
<td>u[i]</td>
<td>Labor employed for per unit production of commodity $i$,</td>
</tr>
<tr>
<td>$k_i$</td>
<td>u[k]</td>
<td>Labor employed for per unit production of commodity $i$,</td>
</tr>
<tr>
<td>$a_{ij}$</td>
<td>a[i][j]</td>
<td>Input-output coefficient for good $i$ used to produce one unit of good $j$,</td>
</tr>
<tr>
<td>$q_{ij}$</td>
<td>q[i][j]</td>
<td>Amount of good $i$ used for production of good $j$,</td>
</tr>
<tr>
<td>$\alpha_i$</td>
<td>alpha[i]</td>
<td>Factor share parameter in value-added component of production function,</td>
</tr>
<tr>
<td>$\Phi_i$</td>
<td>phi[i]</td>
<td>Shift parameter in value-added component of production function,</td>
</tr>
<tr>
<td>$\theta_i$</td>
<td>theta[i]</td>
<td>Share parameter in utility function,</td>
</tr>
<tr>
<td>$p_i$</td>
<td>p[i]</td>
<td>Price of commodity $i$,</td>
</tr>
<tr>
<td>$w_i$</td>
<td>w[i]</td>
<td>Wage rate,</td>
</tr>
<tr>
<td>$r_i$</td>
<td>r[i]</td>
<td>Rental rate,</td>
</tr>
<tr>
<td>$U$</td>
<td>U</td>
<td>Standard neoclassical utility function of a representative consumer,</td>
</tr>
<tr>
<td>$VA_i$</td>
<td>VA[i]</td>
<td>Value-added component of production function $j$,</td>
</tr>
<tr>
<td>$Y$</td>
<td>Y</td>
<td>Level of income for a representative consumer,</td>
</tr>
</tbody>
</table>
B Model Structure

A Model Structure for a Small Open Economy with Intermediate Commodities

**COMMODITY MARKETS**

Utility function: \( U(X_1, X_2) = X_1^{\theta_0} X_2^{1-\theta_0}, \quad 0 < \theta_0 < 1. \)

Production function: \( Q_j = \min \left( \frac{\alpha_j}{\alpha_{ij}}, \frac{V A_j}{\alpha_{ij}} \right), \quad \forall \ i \in I = \{0,1\} \)

Value function: \( VA_i = \Phi_i K_i \alpha_i L_i^{1-\alpha_i}, \quad 0 < \alpha_i < 1, \quad \forall \ i \in I \)

Consumer’s income: \( Y = r \bar{K} + w \bar{L} + EF. \)

Demand: \( X_i = \frac{\theta_i Y}{p_i}, \quad \forall \ i \in I \) (1)

Zero profit conditions: \( p_i = \sum_{j \in J} a_{ij} p_j + rk_i + wd, \quad \forall \ i \in I \) (2)-(3)

In matrix, \( P = (I - AT)^{-1} \)

Market clearing conditions: \( Q_i = \sum_{j \in J} a_{ij} Q_j + X_i + ES_i, \quad \forall \ i \in I \) (6)-(7)

In matrix, \( Q = (I - A)^{-1}(X + ES) \)

**FACTOR MARKETS**

Unit factor demand: \( k_i = \frac{1}{\Phi_i} \left( \frac{\alpha_i}{1-\alpha_i} \right)^{1-\alpha_i} \left( \frac{w_i}{r} \right)^{1-\alpha_i}, \quad \forall \ i \in I \) (8)-(9)

\( l_i = \frac{\alpha_i}{\Phi_i} \left( \frac{\alpha_i}{1-\alpha_i} \right)^{-\alpha_i} \left( \frac{w_i}{r} \right)^{-\alpha_i}, \quad \forall \ i \in I \) (10)-(11)

\( K_i = k_i Q_i, \quad \forall \ i \in I \) (12)-(13)

\( L_i = l_i Q_i, \quad \forall \ i \in I \) (14)-(15)

Market Clearing conditions: \( \sum_{i \in I} K_i = \bar{K}. \)

\( \sum_{i \in I} L_i = \bar{L}. \)

**EXTERNAL SECTOR**

Price equations: \( p_i = \bar{p}_w. \quad \forall \ i \in I \) (18)-(19)

Balance of payment conditions: \( \sum_{i=0}^{12} \bar{p}_w ES_i + EF = 0 \) (20)

**VARIABLES IN THE MODEL**

The 20 endogenous variables: \( X_{i \in I}, Q_{i \in I}, K_{i \in I}, L_{i \in I}, \)

\( k_{i \in I}, l_{i \in I}, p_{i \in I}, w, r, Y, EF, ES_{i \in I}. \)

The 4 exogenous variables: \( \bar{K}, \bar{L}, \bar{p}_w, \bar{L}. \)

The 10 parameters calibrated: \( \theta_{i \in I}, \alpha_{i \in I}, a_{i \in J \in J}, \Phi_{i \in I}. \)