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A CGE MODEL FOR MALAWI: TECHNICAL DOCUMENTATION

Hans Löfgren

International Food Policy Research Institute

Trade and Macroeconomics Division
International Food Policy Research Institute
2033 K Street, N.W.
Washington, D.C. 20006, U.S.A.

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Abstract

Computable General Equilibrium (CGE) models are a class of economywide models that are widely used for policy analysis in developing countries. This paper provides a detailed documentation of an applied CGE model of Malawi – the first ever for Malawi – developed in the context of the project "Collaborative Research and Capacity Strengthening for Multi-Sector Policy Analysis in Malawi and Southern Africa." The purpose of this paper is to serve as a source of background information for analysts using the model in the context of the current project and in the future. The model is built around a 1998 Social Accounting Matrix (SAM) for Malawi, which was developed in the context of the current project, is based on data from the 1998 Integrated Household Survey of Malawi.

The main parts of the paper are a brief, self-contained summary of the model, and a detailed mathematical model statement, presented in a step-by-step fashion. The Appendices present a mathematical model statement in summary form and the 1998 Malawi SAM.

The applied Malawi model can be used for analyses in a relatively wide range of areas, including agricultural, trade, and tax and subsidy policies. It is characterized by a detailed treatment of the labor market and households, permitting model simulations to generate information about the disaggregated impact of policies on household welfare.

As part of the project research activities, the model is used to analyze the impact of external shocks and domestic policies aimed at poverty alleviation. This analysis is presented in a separate document.

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A CGE Model of Malawi: Technical Documentation

Hans Löfgren[1]

1.0 Introduction[2]

CGE models are a class of economywide models that are widely used for policy analysis in developing countries. This paper provides a detailed documentation of an applied Computable General Equilibrium (CGE) model of Malawi – the first ever for Malawi – developed in the context of the project "Collaborative Research and Capacity Strengthening for Multi-Sector Policy Analysis in Malawi and Southern Africa."[3] The purpose of this paper is to serve as a source of background information for analysts using the model in the context of the current project and in the future.[4]

The applied Malawi model can be used for analyses in a relatively wide range of areas, including agricultural, trade, and tax and subsidy policies. It is characterized by a detailed treatment of the labor market and households, permitting model simulations to generate information about the disaggregated impact of policies on household welfare.

As part of the project research activities, the model will be used to analyze agricultural, trade, and fiscal policy issues. This analysis will be presented in separate documents. The model is built around a 1998 Social Accounting Matrix (SAM) for Malawi, developed in the context of the current project and described in detail in Chulu and Wobst (2000), Project Paper No.2. The SAM is based on data from the 1998 Integrated Household Survey of Malawi (the results of which were recently released; see NSO 2000), complementary trade and macro statistics, and a SAM of Malawi for 1994 (Chulu *et al*. 1999).[5]

This paper is organized as follows: Section 2 provides a brief, self-contained summary of the model. Section 3 presents, in a step-by-step fashion, the mathematical model statement. The Appendix presents a mathematical model statement in summary.

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[1] Trade and Macroeconomics Division, IFPRI

[2] The author would like to thank Moataz El-Said for research assistance and Osten Chulu, Ahmed Kamaly, Franklin Simtowe, Hardwick Tchale, and Peter Wobst for comments on an earlier draft.

[3] The primary objective of the project "Collaborative Research and Capacity Strengthening for Multi-Sector Policy Analysis in Malawi and Southern Africa" is to support policymaking in Malawi via collaborative research and training that generate policy-relevant findings and strengthen Malawi's long-run capacity to conduct policy-oriented research. The research component of the project is carried out by researchers from IFPRI and three Malawian institutions: The Agricultural Policy Research Unit of Bunda College of Agriculture, the Reserve Bank of Malawi, and the National Economic Council. Financial support from BMZ, Germany, is gratefully acknowledged.

[4] For a list of general references to CGE modeling, see Löfgren (2000, p. 2).

[5] The model is implemented in a parallel set of files written for the GAMS software; the files include the SAM, the model, simulations, and reports. (The GAMS files are available on request from the author.)

2.0 Model Summary

2.1 Introduction

CGE models may be defined as economy-wide models the solutions to which depict a simultaneous general equilibrium in all markets of the economy. They provide a comprehensive account of the circular flow of payments in the economy. CGE models are widely applied to policy analysis in developing countries. Their comparative advantage lies in the analysis of policies when there is a need to consider links between different producing sectors, links between macro and micro levels, and the disaggregated impact of changes in policies and exogenous shocks on sectoral structure, household welfare, and income distribution.

Like most other CGE models, the Malawi CGE model is solved in a comparative static mode. It provides a simulation laboratory for doing controlled experiments, changing policies and other exogenous conditions, and measuring the impact of these changes. Each solution provides a full set of economic indicators, including household incomes; prices, supplies, and demands for factors and commodities (including foreign trade for the latter); and macroeconomic data.

The model is structured in the tradition of trade-focused CGE models of developing countries described in Dervis, de Melo, and Robinson (1982). It is a further development of the stylized CGE model found in Löfgren (2000, pp. 23-32). To make it appropriate for applied policy analysis, more advanced features have been added, drawing on recent research at IFPRI (see Harris *et al*. 2000). Most importantly, the model has an explicit treatment of trade inputs, which are demanded whenever a commodity is distributed domestically as part of international trade (to or from the border) or as part of domestic trade (from domestic supplier to domestic demander). This feature is particularly important in many African settings where an underdeveloped transport network leads to high transportation costs (*cf*. Ahmed and Rustagi 1993). In addition, the model can handle non-produced imports, *i.e.*, commodities for which the total supply stems from imports. Compared to the stylized CGE model, the current model also has more advanced functional forms for production and consumption to enable it to better capture observed real-world behavior.

The model is built around a 1998 SAM for Malawi (see Project Paper No.2). Most of the model parameters are set endogenously in a manner that assures that the base solution to the model exactly reproduces the values in the SAM – the model is “calibrated” to the SAM. (The remaining parameters, a set of elasticities, are set exogenously.) However, as opposed to the SAM, which is a data framework that records payments, the model contains the behavioral and technical relationships that underlie these payments (Thorbecke 1985, p. 207).

The rest of this section will present the model disaggregation and discuss how the model treats production, domestic institutions (households, enterprises, and the government), the rest of the world and foreign trade, and the so-called system constraints (the markets for commodities and factors, and macro balances for savings-investment and the current account of the rest of the world).

2.2 Model Disaggregation

Table 1 shows the disaggregation of institutions, factors, and activities in the model. The model disaggregation follows the disaggregation of the SAM which, in its turn, was determined by data availability and the planned focus of the analysis on disaggregated household welfare. The disaggregation is relatively detailed for the labor market and households. The fact that land, agricultural capital, and agricultural crop activities are disaggregated along the small-large farmer dimension permits the analysis of policies that are specifically targeted to small farmers.

Table 1: Disaggregation of factors, institutions, and activities

Set	Elements
Labor (8)	• Agricultural (four categories according to educational level: no, low, medium, and high) • Non-agricultural (four categories according to educational level: no, low, medium, and high)
Other factors (5)	• Land (small farmers and large farmers) • Agricultural capital (small farmers and large farmers) • Non-agricultural capital
Households (14)	• Rural agricultural (five land holding sizes: < 0.5 ha, 0.5-1 ha, 1-2 ha, 2-5 ha, and > 5 ha) • Rural non-agricultural (four categories according to educational level of household head: no, low, medium, and high) • Urban agricultural • Urban non-agricultural (four categories according to educational level of household head: no, low, medium, and high)
Other institutions (5)	• Enterprises (agricultural small-farmer, agricultural large-farmer, non-agricultural) • Government • Rest of the world
Agricultural activities (11)	• Small-farmer crops (Maize, Tea, Tobacco, Other) • Large-farmer crops (Tea, Sugar, Tobacco, Other) • Non-crop (Fishing, Livestock, Forestry)
Non-agricultural activities (22)	• Industry (Mining and quarrying, Meat, Dairy, Grain milling, Bakery and confectioneries, Processed sugar, Beverages, Textile and leather, Wood, Paper printing and packaging, Chemicals (incl. fertilizers), Soap, Other manufacturing) • Services (Electricity and water, Construction, Distribution, Hotels, Telecommunications, Financial institutions and insurance, Business services, Public services (incl. government), Personal services)

Production Activities

In the model, the activities carry out production. They receive their revenue from selling the commodities that they produce. These revenues are used to pay for the production inputs: purchases of intermediate inputs and payments of wages (or rents) to primary factors. The model

assumes that the activities maximize profits subject to production functions with neoclassical substitutability for factors and fixed coefficients for intermediate inputs.[6]
Each activity in the model produces a single commodity.[7] In most cases, the activity is the sole producer of its commodity. The only exception is three crop commodities (tea, tobacco, and other crops), each of which is produced by two activities (associated with small and large farmers).

Domestic Institutions

The factor incomes generated in the production process are paid in fixed shares to the enterprises (for capital and land) and the households (for labor). The enterprises, which are viewed as the owners of the stocks of capital and land, use part of their incomes to pay direct taxes, save, and pay the rest of the world (reflecting that foreigners own part of the capital and the land); remaining enterprise incomes are split in fixed shares among the households. The households receive the bulk of their incomes from the factors (labor, land, and capital) they control (either directly or indirectly, via the enterprises). They use these incomes to pay taxes, save and consume (according to demand functions derived from utility maximization).[8]

As part of its current operations, the government receives transfers from the rest of the world, direct taxes (from households, enterprises, and factors) and indirect taxes (import tariffs, export taxes, and sales taxes). The taxes are all imposed according to fixed *ad valorem* rates (*i.e.*, rates expressed as shares of the relevant values – incomes and the value of each commodity that is traded internationally or sold in the domestic market). The government uses this revenue to buy a fixed consumption bundle (including the services of the government bureaucrats), transfer money to households, and save. The nominal value of the transfers is indexed to the CPI. For the basic model version, government savings are treated as a the residual difference between government current revenue and expenditures.[9,10]

The Rest of the World and Foreign Trade

As noted, the rest of the world transfers money to the government and receives transfers from enterprises; these transfers are fixed in foreign currency. In addition, the rest of the world supplies imports and demands exports. The export and import quantities are endogenous to the model: it is assumed that Malawi is able to export or import any desired quantity at international prices that are fixed in foreign currency (the so-called small-country assumption).

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[6] The stylized model of Chapter 5 in Löfgren (2000) used Cobb-Douglas functions which assume a substitution elasticity of unity. This is typically too restrictive. In the current model, substitutability between factors is modeled with CES (Constant Elasticity of Substitution) functions which permit the specification of activity-specific substitution elasticities over a wider range of values.

[7] The model can also handle the case where activities produce more than one commodity but this phenomenon is not represented in the Malawi SAM on which this model is based.

[8] For household consumption, the demand functions are of the LES (Linear Expenditure System) type (as opposed to Cobb-Douglas in the stylized model of Chapter 5 in Löfgren [2000]).

[9] Alternatively, the modeler may specify a fixed government savings target and some other mechanism (adjustments in government consumption or in selected tax rates) through which the government attains this target

[10] In addition, the model assumes that the government, as part of its investment operations, buys fixed quantities of a bundle of commodities for investment purposes. The over-all budget deficit (covering both government current and capital operations) may be computed as the difference between government investment and government savings.

The model also assumes that there are quality differences between commodities that enter foreign trade and those that are produced for domestic use. On the domestic demand side, these quality differences are captured by the assumption of imperfect substitutability between imports and domestic output supplied to the domestic market (in a manner that parallels the way in which capital and labor typically are treated as imperfect substitutes in production). More specifically, if a commodity is imported, all domestic demands – household and government consumption, investment demand, and intermediate demand – are for the same composite commodity. The optimal ratio between the quantities of imports and domestic output that make up each composite commodity is determined by the relative prices of imports and domestic output. Similarly, on the domestic production side, quality differences are captured by the assumption of imperfect transformability between domestic output that is exported and sold domestically. According to this formulation, the export – domestic sales ratio for domestic output is influenced by the relevant relative prices.

This treatment of domestic demand and production grants the domestic price system a certain, realistic degree of independence from international prices and dampens export and import responses to relative price changes. The degree of demand and supply response to changes in these relative prices (and the degree of independence of the domestic prices system from international prices) depends on the values of a set of elasticities specified by the modeler.

2.3 System Constraints: Markets and Macro Balances

The real and nominal flows that were described above may be seen as driven by decisions made by individual agents (households, enterprises, and the government). In addition, the model has to specify the mechanisms used by the modeled economy to satisfy real and nominal system-wide constraints that are not considered by the individual agents. The real constraints represent the domestic commodity and factor markets; the nominal constraints are represented by two macro balances: the current account balance of the rest of the world and the savings-investment balance. The mechanisms through which these constraints are met are often referred to as "closure rules" of the model.

The supply in each composite commodity market is a composite made up of imports and domestic output sold domestically. The demand consists of final demands (for consumption and investment), intermediate demands (from the production activities), and demands for trade inputs. Variations in the price of domestic output supplied to the domestic market assures equilibrium in the domestic output market while, as already noted, variations in import quantities assure equilibrium in the market for imported commodities.

For factor markets, the basic model version assumes that the quantities supplied are fixed (fixing the total level of use of each factor) while the prices of the factors (their wages or rents) equilibrate the quantities demanded with these supply quantities.[11]

[11] The model permits the user to impose alternative specifications with unemployment of selected factors (at fixed wages) and different degrees of mobility of a given factor between different activities (e.g. fixing the quantity of land or the land area for tree crop activities).

In the current account balance of the rest of the world, the basic assumption is that foreign savings (the current account deficit) are fixed; the exchange rate (the price of foreign exchange) is the equilibrating variable. Given that all non-trade items (transfers to or from domestic institutions) are fixed, fixing foreign savings is equivalent to fixing the trade deficit. For the savings-investment balance, the basic model version treats the investment decision as given: the economy allocates fixed quantities of a set of commodities for investment purposes. Given this, the value of savings has to adjust to assure that it equals the investment value. The basic approach is to let the marginal propensity to save vary for one of the domestic non-government institutions.

The model is used for comparative static analysis – it does not contain any dynamic aspects. Its time frame may be termed "equilibrium short-run".[12] It is an equilibrium model since, when used for analysis, it assumes full adjustment from one equilibrium to another. At the same time, it is a short-run model since the capital stock is fixed.

3.0 Mathematical Model Statement

In its mathematical form, the model is a system of simultaneous, non-linear equations. The model is square – the number of equations is equal to the number of variables. This is a necessary (but not a sufficient) condition for the existence of a unique solution.

In this section, the mathematical model statement is presented, equation by equation. The equations are divided into four blocks: prices; production and commodities; institutions; and system constraints. New items (sets, parameters, and variables) are defined the first time they appear in the equations. The notational principles are summarized in Table 2. In addition, parameter and variable names have been chosen to facilitate interpretation; most importantly, commodity and factor quantities start with *q*, commodity prices with *p*, and factor prices with *w*.

Table 2: Notational principles

Item	Notation
Endogenous variables	upper-case Latin letters without a bar
Exogenous variables	upper-case Latin letters with a bar
Parameters	lower-case Latin letters (with or without a bar) or lower-case Greek letters (with or without superscripts)
Set indices	Lower-case Latin letters as subscripts to variables and parameters

Note: Exogenous variables are fixed in the basic model version but may be endogenous in other model versions.

[12] This term is used by Hazell and Norton (1986, p. 300) for agricultural sector models based on similar assumptions.

3.1 Price Block

The price system of the model is rich, primarily as a result of the assumed quality differences between commodities of different origins and destinations (exports, imports, and domestic outputs used domestically). The price block consists of equations in which endogenous model prices are linked to other prices and non-price model variables.

Import price

$$PM_c = pwm_c \cdot (1 + tm_c) \cdot EXR + \sum_{c' \in CT} PQ_{c'} \cdot icm_{c'c}$$

$$\begin{bmatrix} import \\ price \\ (LCU) \end{bmatrix} = \begin{bmatrix} import \\ price \\ (FCU) \end{bmatrix} \cdot \begin{bmatrix} tariff \\ adjust- \\ ment \end{bmatrix} \cdot \begin{bmatrix} exchange\ rate \\ (LCU\ per \\ FCU) \end{bmatrix} + \begin{bmatrix} cost\ of\ trade \\ inputs\ per \\ import\ unit \end{bmatrix} \qquad c \in CM \qquad (1)$$

where

$c \in C$	set of commodities (also referred to as *c'* and *C'*)
$c \in CM (\subset C)$	set of imported commodities
$c \in CT (\subset C)$	set of domestic trade inputs (distribution commodities)
PM_c	domestic import price in LCU (local-currency units; Malawian Kwachas)
pwm_c	world import price in FCU (foreign-currency units)
tm_c	import tariff rate
EXR	exchange rate (LCU per FCU)
PQ_c	composite commodity price (including sales tax)
$icm_{c'c}$	quantity of commodity *c'* as trade input per imported unit of *c*

The import price in LCU is the price paid by domestic users for imported commodities (exclusive of the sales tax). Equation (1) states that it is a transformation of the world price of these imports, considering the exchange rate and import tariffs plus the cost of the trade inputs (the inputs needed to move the commodity from the border to the demander) per unit of the import. The composite price, *PQ*, is the price paid per unit of trade inputs (and, more generally, by all domestic commodity demanders). The domain of the equation is the set of imported commodities (*CM*, a subset of the commodity set, *C*) – the model includes one equation like (1) for every imported commodity.

Note that the notational principles make it possible to distinguish between variables (upper-case Latin letters) and parameters (lower-case Latin letters). This means that the exchange rate and the domestic import price are flexible, while the tariff rate and the world import price are fixed. The fixedness of the world price stems from the "small-country" assumption – for all its imports, Malawi's share of world trade is so small that it faces an infinitely elastic supply curve at the prevailing world price.

Export price

$$PE_c = pwe_c \cdot (1 - te_c) \cdot EXR - \sum_{c' \in CT} PQ_{c'} \cdot ice_{c'c}$$

$$\begin{bmatrix} export \\ price \\ (LCU) \end{bmatrix} = \begin{bmatrix} export \\ price \\ (FCU) \end{bmatrix} \cdot \begin{bmatrix} tax \\ adjust- \\ ment \end{bmatrix} \cdot \begin{bmatrix} exchange\ rate \\ (LCU\ per \\ FCU) \end{bmatrix} - \begin{bmatrix} cost\ of\ trade \\ inputs\ per \\ export\ unit \end{bmatrix} \qquad c \in CE \qquad (2)$$

where

$c \in CE (\subset C)$	set of exported commodities (with domestic production)
PE_c	domestic export price (LCU)
pwe_c	world export price (FCU)
te_c	export tax rate
$ice_{c'c}$	quantity of commodity *c'* as trade input per exported unit of *c*

The domestic export price in LCU is the price received by domestic producers when they sell their output in export markets. This equation is similar in structure to the import price definition. The main difference is that the tax and the cost of trade inputs reduce the price received by the domestic producers of exports (instead of adding to the price paid by domestic demanders of imports). The domain of the equation is the set of exported commodities, all of which are produced domestically. (The model does not include any commodities that are imported for immediate reexportation.)

Demand price of domestic non-traded goods

$$PDD_c = PDS_c + \sum_{c' \in CT} PQ_{c'} \cdot icd_{c'c}$$

$$\begin{bmatrix} domestic \\ demand \\ price \end{bmatrix} = \begin{bmatrix} domestic \\ supply \\ price \end{bmatrix} + \begin{bmatrix} cost\ of\ trade \\ inputs\ per \\ unit\ of \\ domestic\ sales \end{bmatrix} \qquad c \in CX \qquad (3)$$

where

$c \in CX (\subset C)$	set of domestically produced commodities
PDD_c	demand price for commodity produced and sold domestically
PDS_c	supply price for commodity produced and sold domestically
$icd_{c'c}$	quantity of commodity *c'* as trade input per unit of *c* produced and sold domestically

The model also includes distinct prices for domestic output that is used domestically. In the presence of distribution costs (the cost of moving the commodities from the producers to the domestic demanders), it is necessary to distinguish between the prices paid by the demanders and received by the suppliers. Equation (3) defines the demand prices as the supply price plus the cost of trade inputs per unit of domestic sales of the commodity in question.

Absorption

$$PQ_c \cdot QQ_c = \left(PDD_c \cdot QD_c + PM_c \cdot QM_c\right) \cdot \left(1 + tq_c\right)$$

$$\left[absorption\right] = \left(\begin{bmatrix} domestic\ demand \\ price\ times \\ domestic\ sales\ quantity \end{bmatrix} + \begin{bmatrix} domestic\ import \\ price\ times \\ import\ quantity \end{bmatrix}\right) \cdot \begin{bmatrix} sales\ tax \\ adjustment \end{bmatrix} \qquad c \in C \qquad (4)$$

where

QQ_c	quantity of goods supplied to domestic market (composite supply)
QD_c	quantity sold domestically of domestic output
QM_c	quantity of imports of commodity
tq_c	rate of sales tax

Absorption is total domestic spending on a commodity at the prices paid by the domestic demanders (inclusive of the sales tax). It is expressed as the sum of spending on domestic output and imports at the demand prices, *PDD* and *PM*, plus an upward adjustment for the sales tax. (The prices *PDD* and *PM* include the cost of trade inputs but exclude the sales tax; cf. Equations 1 and 3.)

The equation as a whole applies to all commodities; the import part only applies if the commodity is imported. (When the model is written in computer-solvable form, the variables *PM* and *QM* are fixed at zero for commodities that are not elements in the set of imported commodities, *CM*.) Note that this equation could be rewritten as an explicit definition of the composite price (the price paid by domestic demanders, inclusive of the sales tax) by dividing through by *QQ*.

Domestic Output Value

$$PX_c \cdot QX_c = PDS_c \cdot QD_c + PE_c \cdot QE_c$$

$$\begin{bmatrix} producer\ price \\ times\ domestic \\ output\ quantity \end{bmatrix} = \begin{bmatrix} domestic\ supply\ price \\ times \\ domestic\ sales\ quantity \end{bmatrix} + \begin{bmatrix} export\ price \\ times \\ export\ quantity \end{bmatrix} \qquad c \in CX \qquad (5)$$

where

PX_c	aggregate producer price for commodity
QX_c	aggregate quantity of domestic output of commodity
QE_c	quantity of exports

For each commodity produced domestically, domestic output value at producer prices is stated as the value of domestic output sold domestically plus the export value. Domestic sales and exports are valued at the prices received by the suppliers, *PDS* and *PE*, both of which have been adjusted downwards to account for the cost of trade inputs (*cf*. Equations 2 and 3).

The domain limitation to domestically produced commodities (the elements in the set *CX*) has to be stated explicitly given that the model includes the category of imported commodities without domestic production. The export part only applies to exported commodities. (In the computer-solvable model version, the variables *PE* and *QE* are fixed at zero for commodities that are not elements in the set *CE*.) *PX* and *QX* are referred to as "aggregate" values since, for some commodities, they apply to an aggregation of different domestic producers of the same commodity. By dividing through by *QX*, this equation could be rewritten as an explicit definition of *PX*.

Activity Price

$$PA_a = \sum_{c \in CX} PXAC_{ac} \cdot \theta_{ac} \qquad a \in A \qquad (6)$$

$$\begin{bmatrix} \textit{activity} \\ \textit{price} \end{bmatrix} = \begin{bmatrix} \textit{producer prices} \\ \textit{times yields} \end{bmatrix}$$

where

$a \in A$	set of activities
PA_a	activity price (gross revenue per activity unit)
$PXAC_{ac}$	producer price of commodity c for activity a
θ_{ac}	yield of output c per unit of activity a

The gross revenue per activity unit is the return from selling the output (or outputs) of the activity, defined as yields per activity unit multiplied by activity-specific commodity prices, summed over all commodities (to allow for the fact that activities may produce multiple commodities). This revenue is allocated to intermediate inputs, factors, and activity taxes.

Value-added Price

$$PVA_a = PA_a \cdot (1 - ta_a) - \sum_{c \in C} PQ_c \cdot ica_{ca} \qquad a \in A \qquad (7)$$

$$\begin{bmatrix} \textit{value-} \\ \textit{added} \\ \textit{price} \end{bmatrix} = \begin{bmatrix} \textit{activity} \\ \textit{price} \\ \textit{net of tax} \end{bmatrix} - \begin{bmatrix} \textit{intermediate} \\ \textit{input cost} \\ \textit{per activity} \\ \textit{unit} \end{bmatrix}$$

where

PVA_a	value-added price (factor income per unit of activity)
ta_a	tax rate for activity a
ica_{ca}	quantity of c as intermediate input per unit of activity a

The activity value-added price is what remains of the gross revenue, *PA*, after adjustment for the revenue share that is paid in taxes and the cost of intermediate inputs per unit of the activity.

3.2 Production and Commodity Block

This equation block covers domestic production and input use, the allocation of domestic output to exports and the domestic market, the aggregation of the domestic market supply (from imports and domestic output sold domestically), and the definition of the demand for trade inputs that is generated by the distribution process.

Activity Production function

$$QA_a = ad_a \cdot \left(\sum_{f \in F} \delta^a_{f\,a} \cdot QF_{f\,a}{}^{-\rho^a_a} \right)^{-\frac{1}{\rho^a_a}} \qquad a \in A \qquad (8)$$

$$\begin{bmatrix} activity \\ level \end{bmatrix} = CES \begin{bmatrix} factor \\ inputs \end{bmatrix}$$

where

$f \in F$	set of factors
QA_a	quantity (level) of activity
ad_a	efficiency parameter in the CES production function
δ^a_{fa}	CES production function share parameter for factor f in activity a
QF_{fa}	quantity demanded of factor f from activity a
ρ^a_a	CES production function exponent

A CES (Constant Elasticity of Substitution) function is used to capture the relationship between factor use and activity levels.

Factor Demand

$$WF_f \cdot \overline{WFDIST}_{fa} = PVA_a \cdot ad_a \cdot \left(\sum_{f \in F} \delta^a_{fa} \cdot QF_{fa}^{-\rho^a_a} \right)^{-\frac{1}{\rho^a_a}-1} \cdot \delta^a_{fa} \cdot QF_{fa}^{-\rho^a_a} \qquad \begin{matrix} a \in A \\ f \in F \end{matrix} \qquad (9)$$

$$\begin{bmatrix} marginal\ cost \\ of\ \ factor\ \ f \\ in\ activity\ a \end{bmatrix} = \begin{bmatrix} marginal\ revenue \\ product\ of\ \ factor \\ f\ \ in\ activity\ a \end{bmatrix}$$

where

WF_f	average price of factor
$\overline{WFDIST}_{fa}$	wage distortion factor for factor f in activity a (exogenous variable)

Together, Equations 8 and 9 are the first-order conditions for profit maximization subject to the CES production functions. Equation 9 equates the marginal cost of each factor (defined on the left-hand side as the activity-specific factor price) to the marginal revenue from the production generated by the factor (net of taxes and intermediate input costs). The exponent, ρ^a_a, is a transformation of the elasticity of factor substitution: the higher this elasticity, the smaller the value of ρ_a^a and the larger the optimal change in the ratios between different factor quantities in response to changes in relative factor prices.

The fact that the average factor price is an endogenous variable while the activity-specific “wage-distortion” factor is exogenous reflects the treatment of factor markets in the basic model version (see Equation 32 below).

Intermediate Demand

$$QINT_{c\,a} = ica_{c\,a} \cdot QA_a \qquad a \in A,\ c \in C \qquad (10)$$

$$\begin{bmatrix} \textit{intermediate} \\ \textit{demand} \end{bmatrix} = f \begin{bmatrix} \textit{activity} \\ \textit{level} \end{bmatrix}$$

where

$QINT_{ca}$ quantity of commodity c as intermediate input to activity a

For each activity, the demand for intermediate inputs is determined via a standard Leontief formulation as the level of the activity times the intermediate input coefficient.

Output Function

$$QXAC_{a\,c} = \theta_{a\,c} \cdot QA_a \qquad a \in A,\ c \in CX \qquad (11)$$

$$\begin{bmatrix} \text{activity-specific} \\ \text{production of} \\ \text{commodity c} \end{bmatrix} = f \begin{bmatrix} \textit{activity} \\ \textit{level} \end{bmatrix}$$

where

$QXAC_{ac}$ quantity of output of commodity c from activity a

Activity-specific output quantities are determined by activity levels times yields.

Output Aggregation Function

$$QX_c = aac_a \cdot \left(\sum_{a \in A} \delta_{a\,c}^{ac} \cdot QXAC_{a\,c}^{\;-\rho_c^{ac}} \right)^{-\frac{1}{\rho_c^{ac}-1}} \qquad c \in CX \qquad (12)$$

$$\begin{bmatrix} \textit{aggregate} \\ \textit{production of} \\ \textit{commodity c} \end{bmatrix} = CES \begin{bmatrix} \textit{activity-specific} \\ \textit{production of} \\ \textit{commodity c} \end{bmatrix}$$

where

aac_c shift parameter for domestic commodity aggregation function

δ_{ac}^{ac} share parameter for domestic commodity aggregation function

ρ_c^{ac} domestic commodity aggregation function exponent

Aggregate production of any commodity is defined as a CES aggregation of the production levels of the different activities producing the commodity. (*QX* appears as the output, sold at the price *PX* and produced with the inputs *QXAC* which are purchased at the prices *PXAC*.) This is an extension of the Armington treatment (see Equations 14-15 below), which typically is used when the different sources are imports and domestic output, to the case when the different sources are different domestic producers. Economically, this means that demander preferences over outputs from different domestic producers are expressed as a CES function. Imperfect substitutability stems from differences in quality, location, and timing between different producers of what is defined as the same commodity.

First-Order Condition for Output Aggregation Function

$$PXAC_{a\,c} = PX_{\,c} \cdot aac_c \cdot \left(\sum_{a \in A} \delta_{a\,c}^{ac} \cdot QXAC_{a\,c}^{-\rho_c^{ac}} \right)^{-\frac{1}{\rho_c^{ac}}-1} \cdot \delta_{a\,c}^{ac} \cdot QXAC_{a\,c}^{-\rho_c^{ac}-1} \qquad \begin{matrix} a \in A \\ c \in C \end{matrix} \qquad (13)$$

$$\begin{bmatrix} \text{marginal cost of} \\ \text{commodity } c \\ \text{from activity } a \end{bmatrix} = \begin{bmatrix} \text{marginal revenue} \\ \text{product of} \\ \text{commodity } c \\ \text{from activity } a \end{bmatrix}$$

The choice between commodities from different sources is formalized as a production problem with the aggregate output, *QX*, as the output and the disaggregated outputs, *QXAC*, as inputs. Together Equations 12 and 13 states the first-order conditions for maximizing profits from selling the aggregate output, *QX*, at the price *PX* subject to the aggregation function and the disaggregated commodity prices, *PXAC*. A decline in the price *PXAC* of one producer relative to others would shift demand in his/her favor without totally eliminating demand for other, higher-price sources (in a manner that is analogous to the imperfect substitutability that is assumed between imports and domestic output, cf. Equations 14-15). The degree of substitutability between different producers depends on the value of ρ_c^{ac} (which is a transformation of the elasticity of substitution).

Note that, for the case of a single producer of a given commodity, the value of the share parameter, δ_{ac}^{ac}, would be unity and, as a result, *QXAC* = *QX* and *PXAC* = *PX*, irrespective of the values for the elasticity and the exponent.

Composite Supply (Armington) Function

$$QQ_c = aq_c \left(\delta_c^q \cdot QM_c^{-\rho_c^q} + (1 - \delta_c^q) \cdot QD_c^{-\rho_c^q} \right)^{-\frac{1}{\rho_c^q}} \qquad c \in CMX \qquad (14)$$

$$\begin{bmatrix} \text{composite} \\ \text{supply} \end{bmatrix} = f \begin{bmatrix} \text{import quantity, domestic} \\ \text{use of domestic output} \end{bmatrix}$$

where

$c \in CMX (\subset CM)$ set of imported commodities with domestic production

aq_c Armington function shift parameter

δ_c^q	Armington function share parameter
ρ_c^q	Armington function exponent

In a parallel fashion, imperfect substitutability between imports and domestic output sold domestically is also captured by a CES aggregation function in which the composite commodity that is supplied domestically is "produced" by domestic and imported commodities, entering this function as "inputs" (cf. Equations 12 and 13.) This function, with a domain that is limited to commodities that are both imported and produced domestically (the elements in *CMX*), is often called an "Armington" function, named after the originator of the idea of using a CES function for this purpose. The elasticity of substitution between commodities from these two sources is a transformation of ρ_c^q.

Import-Domestic Demand Ratio

$$\frac{QM_c}{QD_c} = \left(\frac{PDD_c}{PM_c} \cdot \frac{\delta_c^q}{1 - \delta_c^q} \right)^{\frac{1}{1+\rho_c^q}} \qquad c \in CMX \qquad (15)$$

$$\begin{bmatrix} \text{import} - \\ \text{domestic} \\ \text{demand ratio} \end{bmatrix} = f \begin{bmatrix} \text{domestic} - \\ \text{import} \\ \text{price ratio} \end{bmatrix}$$

Equation 15 defines the optimal mix between imports and domestic output. Its domain is also limited to imported commodities that are produced domestically. Note that the equation assures that an increase in domestic-import price ratio will generate an increase in the import-domestic demand ratio (*i.e.*, a shift away from the source that became more expensive).[13] Together, Equations 4, 14 and 15 constitute the first-order conditions for cost-minimization given the two prices and subject to the Armington function and a fixed quantity of the composite commodity.

Composite Supply for Non-Imported Commodities

$$QQ_c = QD_c \qquad c \in CNM \qquad (16)$$

$$\begin{bmatrix} \text{composite} \\ \text{supply} \end{bmatrix} = \begin{bmatrix} \text{domestic use of} \\ \text{domestic output} \end{bmatrix}$$

where

$c \in CNM (\subset C)$ set of non-imported commodities

For commodities that are not imported, the Armington function is replaced by the above statement which imposes equality between "composite supply" and domestic output used domestically.

[13] For the Armington function, as the elasticity of substitution between imports and domestic output varies from zero to infinity, the value of ρ_c^q varies from infinity to minus one. According to Equation 15, as the value of ρ_c^q approaches minus one from above, the elasticity of the import-domestic demand ratio with respect to changes in the *PDD-PM* ratio gets larger.

Composite Supply for Non-Produced Imports

$$QQ_c = QM_c \qquad c \in CMNX \qquad (17)$$

$$\begin{bmatrix} composite \\ supply \end{bmatrix} = \begin{bmatrix} imports \end{bmatrix}$$

where

$c \in CMNX (\subset CM)$ imported commodities without domestic production

Similarly, for commodities that are without domestic production, the composite supply is the import supply.

Output Transformation (CET) Function

$$QX_c = at_c \cdot \left(\delta_c^t \cdot QE_c^{\rho_c^t} + (1 - \delta_c^t) \cdot QD_c^{\rho_c^t} \right)^{\frac{1}{\rho_c^t}} \qquad c \in CE \qquad (18)$$

$$\begin{bmatrix} domestic \\ output \end{bmatrix} = CET \begin{bmatrix} export\ quantity,\ domestic \\ use\ of\ domestic\ output \end{bmatrix}$$

where

at_c CET function shift parameter

δ_c^t CET function share parameter

ρ_c^t CET function exponent

Imperfect substitutability between imports and domestic output sold domestically is paralleled by imperfect transformability between domestic output for exports and domestic sales, captured by Equation 18. The CET (constant-elasticity-of-transformation) function, which applies to exported commodities, is identical to a CES function except for negative elasticities of substitution. The elasticity of transformation between the two destinations is a transformation of ρ_c^t for which the lower limit is one. In economic terms, the difference between the Armington and the CET functions is that the arguments in the former are inputs, those in the latter are outputs.

Export-Domestic Supply Ratio

$$\frac{QE_c}{QD_c} = \left(\frac{PE_c}{PDS_c} \cdot \frac{1 - \delta_c^t}{\delta_c^t} \right)^{\frac{1}{\rho_c^t - 1}} \qquad c \in CE \qquad (19)$$

$$\begin{bmatrix} export\text{-} \\ domestic \\ supply\ ratio \end{bmatrix} = f \begin{bmatrix} export\text{-} \\ domestic \\ price\ ratio \end{bmatrix}$$

Equation 19 defines the optimal mix between exports and domestic sales. Equations 5, 18 and 19 constitute the first-order conditions for maximization of producer revenues given the two prices and subject to the CET function and a fixed quantity of domestic output. Note that Equation 19 assures that an increase in export-domestic price ratio will generate an increase in the export-domestic demand ratio (*i.e.*, a shift toward the destination that offers a higher return).[14]

Output Transformation for Non-Exported Commodities

$$QX_c = QD_c \qquad c \in CNE \qquad (20)$$

$$\begin{bmatrix} aggregate \\ domestic \\ output \end{bmatrix} = \begin{bmatrix} domestic\ sales\ of \\ domestic\ output \end{bmatrix}$$

where

$c \in CNE (\subset C)$ non-exported commodities (with domestic production)

For commodities that are not exported, the CET function is replaced by a statement that imposes equality between aggregate domestic output and domestic output sold domestically.

Demand for Trade Inputs

$$QT_c = \sum_{c' \in C'} \left(icm_{c\,c'} \cdot QM_{c'} + ice_{c\,c'} \cdot QE_{c'} + icd_{c\,c'} \cdot QD_{c'} \right) \qquad c \in CT \qquad (21)$$

$$\begin{bmatrix} demand \\ for\ trade \\ inputs \end{bmatrix} = \begin{bmatrix} sum\ of\ trade \\ inputs\ demanded\ for \\ imports,\ exports,\ and \\ domestic\ sales \end{bmatrix}$$

where

QT_c quantity of commodity demanded as trade input

Total demand for trade inputs is the sum of the demands for these inputs that are generated by imports (from moving commodities from the border to domestic demanders), exports (from moving commodities from domestic producers to the border), and domestic sales (from moving commodities from domestic producers to domestic demanders). In all three cases, fixed quantities of one or more trade inputs are required per unit of the traded commodity.

[14] For the CET function, as the elasticity of transformation between exports and domestic sales varies from zero to infinity, the value of ρ_c^t varies from infinity to one. According to Equation 19, as the value of ρ_c^t approaches one from above, the elasticity of the export-domestic demand ratio with respect to changes in the *PE-PDD* ratio gets larger.

3.3 Institution Block

Factor Income

$$YF_{i\,f} = shry_{i\,f} \cdot \left(1 - \overline{TY}_f\right) \cdot \sum_{a \in A} WF_f \cdot \overline{WFDIST}_{f\,a} \cdot QF_{f\,a} \qquad i \in ID,\; f \in F \qquad (22)$$

$$\begin{bmatrix} \text{income of} \\ \text{institution } i \\ \text{from factor } f \end{bmatrix} = \begin{bmatrix} \text{share of income} \\ \text{of factor } f \text{ to} \\ \text{institution } i \end{bmatrix} \cdot \begin{bmatrix} \text{income of factor } f \\ \text{(net of tax)} \end{bmatrix}$$

where

$i \in I$	set of institutions (households, enterprises, government, and rest of world)
$i \in ID (\subset I)$	set of domestic institutions (households, enterprises, and government)
YF_{if}	transfer of income to domestic institution i from factor f
$shry_{if}$	share for domestic institution i in income of factor f
$\overline{TY}_i$ or $\overline{TY}_f$	direct tax rate for domestic institution i or factor f (exogenous variable)

Factor incomes (net of direct taxes) are split among domestic institutions in fixed shares. (To assure that the total factor income is distributed, it is necessary that $\sum_{i \in ID} shry_{if} = 1$.)

Institution Income

$$YI_i = \sum_{f \in F} YF_{i\,f} + \sum_{i' \in IDNG'} TR_{i\,i'} + \overline{tr}_{i\,gov} + EXR \cdot \overline{tr}_{i\,row} \qquad i \in IDNG \qquad (23)$$

$$\begin{bmatrix} \text{income of} \\ \text{institution } i \end{bmatrix} = \begin{bmatrix} \text{factor} \\ \text{income} \end{bmatrix} + \begin{bmatrix} \text{transfers} \\ \text{from other} \\ \text{institutions} \end{bmatrix} + \begin{bmatrix} \text{government} \\ \text{transfers} \end{bmatrix} + \begin{bmatrix} \text{transfers} \\ \text{from RoW} \end{bmatrix}$$

where

$i \in IDNG (\subset ID)$	set of domestic non-gov. institutions (households and enterprises)
YI_i	income of domestic non-government institution
$TR_{ii'}$	transfers from domestic non-government inst. i' to domestic inst. i
$\overline{tr}_{ii'}$	transfer from institution i to institution i'

The total income of any domestic non-government institution is the sum of factor incomes (defined in Equation 22), transfers from other domestic non-government institutions (defined in the following Equation 24), and exogenous transfers from the government and the rest of the world.

Intra-Institutional Transfers

$$TR_{i\,i'} = shrtr_{i\,i'} \cdot (1 - MPS_{i'}) \cdot (1 - \overline{TY}_{i'}) \cdot \left(YI_{i'} - EXR \cdot \overline{tr}_{row\,i'}\right) \qquad i \in ID,\; i' \in IDNG \qquad (24)$$

$$\begin{bmatrix} \text{transfer from} \\ \text{institution } i' \text{ to } i \end{bmatrix} = \begin{bmatrix} \text{share of income} \\ \text{of institution } i' \\ \text{transfered to } i \end{bmatrix} \cdot \begin{bmatrix} \text{income of institution } i' \\ \text{net of savings, direct taxes,} \\ \text{and transfers to RoW} \end{bmatrix}$$

where

$shrtr_{ii'}$	share of domestic inst. i in income of domestic non-government inst. i'
MPS_i	marginal propensity to save for domestic non-government institution (exogenous variable)

Transfers from domestic non-government institutions to other domestic institutions (including the government) are paid in fixed shares of the total institutional income after transfers to the rest of the world and deduction of the fixed income shares that are paid in taxes or saved.

Household Consumption Expenditures

$$EH_h = \left(1 - \sum_{i \in ID} shrtr_{ih}\right) \cdot \left(1 - MPS_h\right) \cdot (1 - \overline{TY}_h) \cdot \left(YI_h - EXR \cdot \overline{tr}_{row\,h}\right) \qquad h \in H \qquad (25)$$

$$\begin{bmatrix} \textit{household disposable} \\ \textit{income (for consumption)} \end{bmatrix} = \begin{bmatrix} \textit{household income} \\ \textit{net of savings, direct taxes,} \\ \textit{and transfers to RoW} \\ \textit{and other institutions} \end{bmatrix}$$

where

$h \in H (\subset IDNG)$	set of households
EH_h	consumption spending for household

Among the domestic non-government institutions, only the households demand commodities. In this equation, the total value of consumption spending is defined as income left over after transfers to other domestic institutions, savings, direct taxes, and transfers to the rest of the world.

Household Consumption Demand

$$QH_{ch} = \gamma_{ch} + \frac{\beta_{ch} \cdot \left(EH_h - \sum_{c \in C} PQ_c \cdot \gamma_{ch}\right)}{PQ_c} \qquad \begin{matrix} c \in C \\ h \in H \end{matrix} \qquad (26)$$

$$\begin{bmatrix} \textit{quantity of} \\ \textit{household demand} \\ \textit{for commodity } c \end{bmatrix} = f \begin{bmatrix} \textit{household} \\ \textit{disposable} \\ \textit{income, price} \end{bmatrix}$$

where

QH_{ch}	quantity consumed of commodity c by household h
γ_{ch}	subsistence consumption of commodity c for household h
β_{ch}	marginal share of consumption spending of household h on commodity c

It is assumed that each household maximizes a "Stone-Geary" utility function subject to an expenditure constraint.[15] The first-order conditions for utility maximization subject to an income constraint are summarized in the above demand functions. This demand system is referred to as the Linear Expenditures System (LES) – if Equation 26 is multiplied on both sides by *PQ*, spending on individual commodities is a linear function of total consumption spending, *EH*.

Private Investment Demand

$$QINV_c = \overline{qinv}_c \cdot \overline{IADJ}$$

$$\begin{bmatrix} \text{private investment} \\ \text{demand for} \\ \text{commodity } c \end{bmatrix} = \begin{bmatrix} \text{base-year private} \\ \text{investment times} \\ \text{adjustment factor} \end{bmatrix} \qquad c \in C \qquad (27)$$

where

$QINV_c$	quantity of investment demand for commodity
$\overline{qinv}_c$	base-year quantity of private investment demand
$\overline{IADJ}$	investment adjustment factor (exogenous variable)

Private investment demand is defined as the base-year quantity multiplied by an adjustment factor. For the basic model version, the adjustment factor is exogenous and the quantity of private investment fixed (see discussion of Equation 35).

Government Consumption Demand

$$QG_c = \overline{qg}_c \cdot \overline{GADJ}$$

$$\begin{bmatrix} \text{government} \\ \text{consumption} \\ \text{demand for} \\ \text{commodity } c \end{bmatrix} = \begin{bmatrix} \text{base-year government} \\ \text{consumption} \\ \text{times} \\ \text{adjustment factor} \end{bmatrix} \qquad c \in C \qquad (28)$$

where

QG_c	government consumption demand for commodity
$\overline{qg}_c$	base-year quantity of government demand
$\overline{GADJ}$	government consumption adjustment factor (exogenous variable)

Similarly, government consumption demand (in which the main component is spending on the services provided by the government labor force) is also defined as the base-year quantity multiplied by an adjustment factor. This factor is also exogenous and, hence, the quantity of government consumption fixed (see discussion of Equation 31).

---

[15] The Stone-Geary utility function may be written as follows: $U_h = \prod_{c \in C} (QH_{ch} - \gamma_{ch})^{\beta_{ch}}$, where U_h is the utility of household h and the rest of the notation is the same as in the model. For further details, see Dervis *et al.* (1982, pp. 482-485).

Government Revenue

$$
\begin{aligned}
YG = & \sum_{f\in F} YF_{gov\,f} + \sum_{i\in I} \overline{TY}_i \cdot YI_i + \sum_{i\in IDNG} TR_{gov\,i} \cdot YI_i + EXR \cdot \overline{tr}_{gov\,row} \\
& + \sum_{f\in F} \overline{TY}_f \cdot \sum_{a\in A} WF_f \cdot \overline{WFDIST}_{fa} \cdot QF_{fa} \\
& + \sum_{c\in C} tq_c \left(PDD_c \cdot QD_c + PM_c QM_c \right) + \sum_{a\in A} ta_a \cdot PA_a \cdot QA_a \\
& + \sum_{c\in C} tm_c \cdot EXR \cdot pwm_c \cdot QM_c + \sum_{c\in C} te_c \cdot EXR \cdot pwe_c \cdot QE_c
\end{aligned} \tag{29}
$$

$$
\begin{bmatrix} government \\ revenue \end{bmatrix} = \begin{bmatrix} factor \\ income \end{bmatrix} + \begin{bmatrix} direct\ taxes \\ from \\ institutions \end{bmatrix} + \begin{bmatrix} transfers\ from \\ domestic \\ institutions \end{bmatrix} + \begin{bmatrix} transfers \\ from \\ RoW \end{bmatrix}
+ \begin{bmatrix} direct\ taxes \\ from\ factors \end{bmatrix} + \begin{bmatrix} sales \\ tax \end{bmatrix} + \begin{bmatrix} activity \\ tax \end{bmatrix} + \begin{bmatrix} import \\ tariffs \end{bmatrix} + \begin{bmatrix} export \\ taxes \end{bmatrix}
$$

where

YG government revenue

Total government revenue is the sum of government incomes from factors, institutional transfers (including transfers from the rest of the world), and taxes (direct taxes on factor and institutional incomes; sales, activity, import, and export taxes on trade and production).

Government Expenditures

$$
EG = \sum_{c\in C} PQ_c \cdot QG_c + \sum_{i\in IDNG} \overline{tr}_{i\,gov} + EXR \cdot \overline{tr}_{row\,gov} \tag{30}
$$

$$
\begin{bmatrix} government \\ spending \end{bmatrix} = \begin{bmatrix} government \\ consumption \end{bmatrix} + \begin{bmatrix} transfers\ to \\ domestic \\ institutions \end{bmatrix} + \begin{bmatrix} transfers \\ to\ RoW \end{bmatrix}
$$

where

EG government expenditures

Total government spending is the sum of government spending on consumption and transfers.

Government Savings

$$
GSAV = YG - EG \tag{31}
$$

$$
\begin{bmatrix} government \\ savings \end{bmatrix} = \begin{bmatrix} government \\ revenue \end{bmatrix} - \begin{bmatrix} government \\ expenditures \end{bmatrix}
$$

where

GSAV government savings

Government savings is defined as the difference between government revenue and (current) government expenditures (not including government investment spending). For the basic model, government savings is an endogenous variable; in other versions, it may be fixed while another variable (which in the basic model version is exogenous) is unfixed, for example the direct tax rate of one the domestic institutions ($\overline{TY}_i$ for one of the elements in the set *IDNG*) or the adjustment factor for government consumption ($\overline{GADJ}$). Variations in the unfixed variable assures that the exogenous government savings target is reached.

3.4 System Constraint Block

Factor Market

$$\sum_{a \in A} QF_{f\,a} = \overline{QFS}_f \qquad f \in F \qquad (32)$$

$$\begin{bmatrix} demand\ \ for \\ factor\ \ f \end{bmatrix} = \begin{bmatrix} supply\ \ of \\ factor\ \ f \end{bmatrix}$$

where

$\overline{QFS}_f$ quantity supplied of factor (exogenous variable)

This equation imposes equality between the total quantity demanded and total quantity supplied for each factor. In the basic model version, all demand variables are flexible while the supply variable is fixed. The factor wage, WF_f, is the equilibrating variable that assures that this equation is satisfied – an increase in WF_f raises the wage paid by each activity, $WF_f \cdot \overline{WFDIST}_{f\,a}$, which is inversely related to the quantities of factor demand, $QF_{f\,a}$. All factors are mobile between the demanding activities.

Other formulations may be used. For example, to specify the case with unemployment at a given wage for a factor, the supply variable for the factor is unfixed (QFS_f) while its economy-wide wage is fixed ($\overline{WF}_f$). If so, the model remains square (one endogenous variable is added but another one removed). Each activity is free to employ the quantity it desires ($QF_{f\,a}$) at a fixed wage ($\overline{WF}_f \cdot \overline{WFDIST}_{f\,a}$). The free supply variable, QFS_f, records the total employment level.

Alternatively, to specify the case of a fully segmented factor market with fixed factor demands for each activity (for example short-run fixity of non-agricultural capital use), the variables for factor demand and the economy-wide wage are fixed (written $\overline{QF}_{f\,a}$ and $\overline{WF}_f$) while the variables for supply and wage distortions are unfixed (written QFS_f and $WFDIST_{f\,a}$). The model remains square (the economy-wide wage variable and a set of activity-specific factor-demand variables are fixed; the supply variable and a set of activity-specific wage-distortion variables are unfixed). Activity-specific wages, $\overline{WF}_f \cdot WFDIST_{f\,a}$, vary to assure that the fixed activity-specific employment level, $\overline{QF}_{f\,a}$ is consistent with profit-maximization (cf. Equation 9). For this formulation, the endogenous supply variable merely records the total employment level.

Composite Commodity Markets

$$QQ_c = \sum_{a \in A} QINT_{c\,a} + \sum_{h \in H} QH_{c\,h} + QG_c + QT_c + QINV_c + qginv_c + qdst_c \qquad c \in C \qquad (33)$$

$$\begin{bmatrix} composite \\ supply \end{bmatrix} = \begin{bmatrix} intermediate \\ use \end{bmatrix} + \begin{bmatrix} household \\ consumption \end{bmatrix} + \begin{bmatrix} government \\ consumption \end{bmatrix} + \begin{bmatrix} trade \\ input\ use \end{bmatrix} + \begin{bmatrix} private \\ investment \end{bmatrix} + \begin{bmatrix} government \\ investment \end{bmatrix} + \begin{bmatrix} stock \\ change \end{bmatrix}$$

where

$qdst_c$ quantity of stock change

$qginv_c$ quantity of government investment demand

This equation imposes equality between quantities supplied (from Equations 14-16) and demanded. The demand side includes endogenous terms (from Equations 10, 21, 26, and 27) and two new exogenous investment items. The market-clearing variables are the quantities of import supply, *QM*, for the part of supply that is represented by imports and the domestic demand price, *PDD*, for the domestic supply.

Current Account Balance for RoW (in Foreign Currency)

$$\sum_{c \in C} pwm_c \cdot QM_c + \sum_{i \in ID} \overline{tr}_{row\ i} = \sum_{c \in C} pwe_c \cdot QE_c + \sum_{i \in ID} \overline{tr}_{i\ row} + \overline{FSAV} \qquad (34)$$

$$\begin{bmatrix} import \\ spending \end{bmatrix} + \begin{bmatrix} transfers \\ to\ RoW \end{bmatrix} = \begin{bmatrix} export \\ revenue \end{bmatrix} + \begin{bmatrix} transfers \\ from\ RoW \end{bmatrix} + \begin{bmatrix} foreign \\ savings \end{bmatrix}$$

where

$\overline{FSAV}$ foreign savings (FCU) (exogenous variable)

The current-account balance (which is expressed in foreign currency) imposes equality between the country's spending and earning of foreign exchange. For the basic model version, foreign savings is fixed; the exchange rate (*EXR*) serves the role of clearing the current-account balance. For example, other things being equal, an increase in the exchange rate (depreciation) would remove any deficit (in excess of $\overline{FSAV}$) by (a) reducing foreign exchange spending on imports (via a cut in import quantities at fixed world prices); and (b) increasing foreign exchange earnings from exports (via a boost in export quantities at fixed world prices) (*cf.* Equations 15 and 19). The fact that all items except imports and exports are fixed means that, in effect, the trade deficit also is fixed.

Alternatively, the exchange rate may be fixed and foreign savings unfixed. If so, the trade deficit is free to vary.

Savings-Investment Balance

$$\sum_{c \in C} PQ_c \cdot QINV_c + \sum_{c \in C} PQ_c \cdot qdst_c + \sum_{c \in C} PQ_c \cdot qginv_c$$
$$= \sum_{i \in IDNG} MPS_i \cdot \left(1 - \overline{TY}_i\right) \cdot \left(YI_i - EXR \cdot \overline{tr}_{row\, i}\right) + GSAV + EXR \cdot \overline{FSAV} \quad (35)$$
$$\begin{bmatrix} \text{private} \\ \text{investment} \end{bmatrix} + \begin{bmatrix} \text{stock} \\ \text{change} \end{bmatrix} + \begin{bmatrix} \text{government} \\ \text{investment} \end{bmatrix} = \begin{bmatrix} \text{non-govern-} \\ \text{ment savings} \end{bmatrix} + \begin{bmatrix} \text{government} \\ \text{savings} \end{bmatrix} + \begin{bmatrix} \text{foreign} \\ \text{savings} \end{bmatrix}$$

This equation states that the total investment value (the sum of the value of private and government investment, which constitute "gross fixed capital formation", and the value of stock changes) equals total savings (the sum of savings from domestic non-government institutions, the government, and the rest of the world, with the latter converted into domestic currency).

In the basic model version, the MPS variables for all domestic non-government institutions except the non-agricultural enterprise are fixed (in a side-condition). The savings rate and, hence, the savings value of this institution is free to perform the role of balancing aggregate savings and investment values. All other items in the savings-investment balance are fixed or have to adjust to satisfy other conditions. Given that the balancing role was performed by the savings-side, this closure represents a case of "investment-driven" savings.

If, alternatively, the investment adjustment variable, which is exogenous in the basic model version ($\overline{IADJ}$), were unfixed and the MPS of the non-agricultural enterprise fixed, investment would be "savings-driven."

Investment-driven closures with a more evenly spread adjustment burden are also possible, for example, the imposition of an equal percentage point change in the savings rates for all households.

Price Normalization

$$\sum_{c \in C} PQ_c \cdot cwts_c = cpi \quad (36)$$
$$\begin{bmatrix} \text{price times} \\ \text{weights} \end{bmatrix} = \begin{bmatrix} CPI \end{bmatrix}$$

where

$cwts_c$	weight of commodity c in the CPI
cpi	consumer price index (CPI)

The model that has been presented up to this point is homogeneous of degree zero in prices – if one equilibrium solution exists, there is an infinite number of solutions (each of which has the same relative prices). To assure that only one solution exists, the above price normalization equation, which fixes a measure of the consumer price index (CPI), has been added. Given this definition of the price normalization equation, all simulated price changes can be directly interpreted as changes vis-a-vis the CPI. (Alternatively, it would have been possible to fix one price variable, for example a wage.)

Up to this point, the model that has been stated is not square; the number of equations exceeds the number of variables by one. Moreover, the model satisfies Walras' law in that one equation is functionally dependent on the others and can be dropped. (The savings-investment balance or a commodity-market equilibrium condition is commonly eliminated.) After eliminating one equation, the model is square and, in the absence of errors in formulation, a unique solution typically exists. Instead of dropping one equation, it is also be possible to add one variable (in one or more equations). Its solution value should be zero – if not, one or more equations are not satisfied and a general equilibrium solution has not been found.[16]

At this point, a complete and self-contained model has been presented. In the current version, the remaining three equations (and the three new variables that appear in them) are superfluous (but innocuous). The reason for including them is that they permit the formulation of model versions that impose a more balanced adjustment in the components of absorption in response to shocks. This topic is discussed after the last equation.

Total Absorption

$$\begin{aligned} TABS = &\sum_{h \in H} \sum_{c \in C} PQ_c \cdot QH_{c\,h} + \sum_{c \in C} PQ_c \cdot QG_c + \sum_{c \in C} PQ_c \cdot QINV_c \\ &+ \sum_{c \in C} PQ_c \cdot qdst_c + \sum_{c \in C} PQ_c \cdot qginv_c \end{aligned} \qquad (37)$$

$$\begin{bmatrix} total \\ absorption \end{bmatrix} = \begin{bmatrix} household \\ consumption \end{bmatrix} + \begin{bmatrix} government \\ consumption \end{bmatrix} + \begin{bmatrix} private \\ investment \end{bmatrix} + \begin{bmatrix} stock \\ change \end{bmatrix} + \begin{bmatrix} government \\ investment \end{bmatrix}$$

where
TABS total nominal absorption

Total absorption is measured as the total value of domestic final demands. The new variable, *TABS*, records this value.

Ratio of Investment to Absorption

$$INVSHR \cdot TABS = \sum_{c \in C} PQ_c \cdot QINV_c + \sum_{c \in C} PQ_c \cdot qginv_c + \sum_{c \in C} PQ_c \cdot qdst_c \qquad (38)$$

$$\begin{bmatrix} investment\text{-} \\ absorption \\ ratio \end{bmatrix} \cdot \begin{bmatrix} total \\ absorption \end{bmatrix} = \begin{bmatrix} private \\ investment \end{bmatrix} + \begin{bmatrix} government \\ investment \end{bmatrix} + \begin{bmatrix} stock \\ change \end{bmatrix}$$

where
INVSHR investment share in nominal absorption

[16] This approach is followed in the GAMS version of this model. A variable called WALRAS is added to the savings-investment balance.

The right-hand side of this equation defines the total investment value (*cf*. Equation 35). On the left-hand side total absorption is multiplied by a new free variable, $INVSHR$. At equilibrium, this variable measures the ratio between investment and absorption.

Ratio of Government Consumption to Absorption

$$GOVSHR \cdot TABS = \sum_{c \in C} PQ_c \cdot QG_c \qquad (39)$$

$$\begin{bmatrix} government \\ consumption\text{-} \\ absorption \\ ratio \end{bmatrix} \cdot \begin{bmatrix} total \\ absorption \end{bmatrix} = \begin{bmatrix} government \\ consumption \end{bmatrix}$$

where

$GOVSHR$	government consumption share in nominal absorption

This final equation is similar to Equation 38 except for that investment is replaced by government consumption. The right-hand side defines the value of government consumption (*cf*. Equation 30). On the left-hand side, total absorption is multiplied by a new free variable, $GOVSHR$, which measures the ratio between government consumption and absorption.

The presence of Equations 37-39 and three new variables makes it possible to specify a "balanced" macro adjustment that may be preferable for model simulations aimed at generating plausible real-world responses to shocks that lead to significant changes in total absorption (for example as a result of a terms-of-trade shock). In the current model formulation (with $\overline{IADJ}$ and $\overline{GADJ}$ as exogenous variables), the entire shock will be absorbed by household consumption.[17] In the alternative closure with savings-driven investment under which all savings rates are fixed and the investment adjustment factor flexible ($\overline{MPS}_i$ and $IADJ$), the adjustment burden would fall on investment.

Under the alternative, balanced closure, the investment and government absorption shares are both fixed at base levels ($\overline{INVSHR}$ and $\overline{GOVSHR}$) while the adjustment factors are unfixed ($IADJ$ and $GADJ$). In other respects, the basic model formulation is retained (including a flexible savings rate for one or a set of domestic non-government institution).

In this setting, any change in total absorption would, in nominal terms, be spread evenly across the three components of absorption. (Given the shares for investment and government consumption, the share for household consumption is implicitly defined.) Adjustments in non-government savings would balance the savings and investment values. The scope of the savings adjustment, which would be influenced by changes in investment and government consumption (for the latter via changes in government savings), would determine the space for household consumption.

[17] However, for simulations with single-period models (like the current model) aimed at exploring welfare impacts of exogenous shocks, this closure is sometimes preferable since the model would not be able to capture future welfare changes associated with current changes in investment.

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Appendix: Mathematical Model Statement in Summary Form

The mathematical summary statement is found in Table A1. It starts with alphabetical lists of individual items (sets, parameters, exogenous variables, and endogenous variables) followed by a statement of the equations in the same order as in Section 3.

Table A.1: Mathematical summary statement for the Malawi CGE model

SETS

Symbol	Explanation	Symbol	Explanation
$a \in A$	activities	$c \in CMNX (\subset CM)$	imported commodities without domestic production
$c \in C$	commodities	$c \in CT (\subset C)$	domestic trade inputs (distribution commodities)
$c \in CX (\subset C)$	domestically produced commodities	$f \in F$	factors
$c \in CE (\subset C)$	exported commodities (with domestic production)	$i \in I$	institutions (households, enterprises, government, and rest of world)
$c \in CNE (\subset C)$	non-exported commodities (with domestic production)	$i \in ID (\subset I)$	domestic institutions (households, enterprises, and government
$c \in CM (\subset C)$	imported commodities	$i \in IDNG (\subset ID)$	domestic non-government institutions (households and enterprises)
$c \in CNM (\subset C)$	non-imported commodities	$h \in H (\subset IDNG)$	households
$c \in CMX (\subset CM)$	imported commodities with domestic production		

PARAMETERS

aac_c	shift parameter for domestic commodity aggregation function	$qdst_c$	quantity of stock change
ad_a	efficiency parameter in the CES production function	$\overline{qg}_c$	base-year quantity of government demand
aq_c	Armington function shift parameter	$qginv_c$	quantity of government investment demand
at_c	CET function shift parameter	$\overline{qinv}_c$	base-year quantity of private investment demand
cpi	consumer price index	$shrtr_{ii'}$	share of domestic inst. i in income of domestic non-government inst. i'
$cwts_c$	weight of commodity c in the CPI	$shry_{if}$	share of domestic institution i in income of factor f
ica_{ca}	quantity of c as intermediate input per unit of activity a	ta_a	tax rate for activity a
$icd_{c'c}$	quantity of commodity *c'* as trade input per unit of *c* produced and sold domestically	te_c	export tax rate
$ice_{c'c}$	quantity of commodity *c'* as trade input per exported unit of *c*	tm_c	import tariff rate

Table A.1: Mathematical summary statement for the Malawi CGE model

$icm_{c'c}$	quantity of commodity *c'* as trade input per imported unit of *c*	tq_c	rate of sales tax
pwe_c	export price (foreign currency)	$\overline{tr}_{ii'}$	transfer from institution i to institution i'
pwm_c	import price (foreign currency)		

<u>Greek Letters</u>

α_{fa}	share of value-added to factor f in activity a	γ_{ch}	subsistence consumption of commodity c for household h
β_{ch}	marginal share of consumption spending of household on commodity c	θ_{ac}	yield of output c per unit of activity a
δ^{a}_{fa}	CES production function share parameter for factor f in activity a	ρ^{a}_{a}	CES production function exponent
δ^{ac}_{ac}	share parameter for domestic commodity aggregation function	ρ^{ac}_{c}	domestic commodity aggregation function exponent
δ^{q}_{c}	Armington function share parameter	ρ^{q}_{c}	Armington function exponent
δ^{t}_{c}	CET function share parameter	ρ^{t}_{c}	CET function exponent

EXOGENOUS VARIABLES

$\overline{FSAV}$	foreign savings (FCU)	$\overline{TY}_i$ or $\overline{TY}_f$	direct tax rate for domestic institution i or factor f
$\overline{GADJ}$	government consumption adjustment factor	$\overline{WFDIST}_{fa}$	wage distortion factor for factor f in activity a
$\overline{IADJ}$	investment adjustment factor		

ENDOGENOUS VARIABLES

EG	government expenditures	QE_c	quantity of exports
EH_h	consumption spending for household	QF_{fa}	quantity demanded of factor f from activity a
EXR	exchange rate (LCU per unit of FCU)	QG_c	government consumption demand for commodity
$GOVSHR$	government consumption share in nominal absorption	QH_{ch}	quantity consumed of commodity c by household h
$GSAV$	government savings	$QINT_{ca}$	quantity of commodity c as intermediate input to activity a
$INVSHR$	investment share in nominal absorption	$QINV_c$	quantity of investment demand for commodity
MPS_i	marginal propensity to save for domestic non-government institution	QM_c	quantity of imports of commodity
PA_a	activity price (unit gross revenue)	QQ_c	quantity of goods supplied to domestic market (composite supply)
PDD_c	demand price for commodity produced and sold domestically	QT_c	quantity of commodity demanded as trade input
PDS_c	supply price for commodity produced and sold domestically	QX_c	aggregated quantity of domestic output of commodity
PE_c	export price (domestic currency)	$QXAC_{ac}$	quantity of output of commodity c from activity a
PM_c	import price (domestic currency)	$TABS$	total nominal absorption

Table A.1: Mathematical summary statement for the Malawi CGE model

PQ_c	composite commodity price	$TR_{ii'}$	transfers from domestic non-government institution I' to domestic institution i
PVA_a	value-added price (factor income per unit of activity)	WF_f	economy-wide factor wage
PX_c	aggregate producer price for commodity	YF_{if}	transfer of income to domestic institution i from factor f
$PXAC_{ac}$	producer price of commodity c for activity a	YG	government revenue
QA_a	quantity (level) of activity	YI_i	income of domestic non-government institution
QD_c	quantity sold domestically of domestic output		

EQUATIONS*

#	Equation	Domain	Description
Price Block			
1	$PM_c = pwm_c \cdot (1+tm_c) \cdot EXR + \sum_{c' \in CT} PQ_{c'} \cdot icm_{c'c}$ $\begin{bmatrix} import \\ price \\ (LCU) \end{bmatrix} = \begin{bmatrix} import \\ price \\ (FCU) \end{bmatrix} \cdot \begin{bmatrix} tariff \\ adjust- \\ ment \end{bmatrix} \cdot \begin{bmatrix} exchange\ rate \\ (LCU\ per \\ FCU) \end{bmatrix} + \begin{bmatrix} cost\ of\ trade \\ inputs\ per \\ import\ unit \end{bmatrix}$	$c \in CM$	Import Price
2	$PE_c = pwe_c \cdot (1-te_c) \cdot EXR - \sum_{c' \in CT} PQ_{c'} \cdot ice_{c'c}$ $\begin{bmatrix} export \\ price \\ (LCU) \end{bmatrix} = \begin{bmatrix} export \\ price \\ (FCU) \end{bmatrix} \cdot \begin{bmatrix} tax \\ adjust- \\ ment \end{bmatrix} \cdot \begin{bmatrix} exchange\ rate \\ (LCU\ per \\ FCU) \end{bmatrix} - \begin{bmatrix} cost\ of\ trade \\ inputs\ per \\ export\ unit \end{bmatrix}$	$c \in CE$	Export Price
3	$PDD_c = PDS_c + \sum_{c' \in CT} PQ_{c'} \cdot icd_{c'c}$ $\begin{bmatrix} domestic \\ demand \\ price \end{bmatrix} = \begin{bmatrix} domestic \\ supply \\ price \end{bmatrix} + \begin{bmatrix} cost\ of\ trade \\ inputs\ per \\ unit\ of \\ domestic\ sales \end{bmatrix}$	$c \in CX$	Demand price of domestic non-traded goods
4	$PQ_c \cdot QQ_c = (PDD_c \cdot QD_c + PM_c \cdot QM_c) \cdot (1+tq_c)$ $\begin{bmatrix} absorption \end{bmatrix} = \left(\begin{bmatrix} domestic\ demand\ price \\ times \\ domestic\ sales\ quantity \end{bmatrix} + \begin{bmatrix} import\ price \\ times \\ import\ quantity \end{bmatrix} \right) \cdot \begin{bmatrix} sales\ tax \\ adjustment \end{bmatrix}$	$c \in C$	Absorption
5	$PX_c \cdot QX_c = PDS_c \cdot QD_c + PE_c \cdot QE_c$ $\begin{bmatrix} producer\ price \\ times\ domestic \\ output\ quantity \end{bmatrix} = \begin{bmatrix} domestic\ supply\ price \\ times \\ domestic\ sales\ quantity \end{bmatrix} + \begin{bmatrix} export\ price \\ times \\ export\ quantity \end{bmatrix}$	$c \in CX$	Domestic Output Value

Table A.1: Mathematical summary statement for the Malawi CGE model

6	$PA_a = \sum_{c \in CX} PXAC_{a\,c} \cdot \theta_{a\,c}$ $\begin{bmatrix} activity \\ price \end{bmatrix} = \begin{bmatrix} producer\ prices \\ times\ yields \end{bmatrix}$	$a \in A$	Activity Price
7	$PVA_a = PA_a \cdot (1 - ta_a) - \sum_{c \in C} PQ_c \cdot ica_{c\,a}$ $\begin{bmatrix} value\text{-} \\ added \\ price \end{bmatrix} = \begin{bmatrix} activity \\ price \\ net\ of\ tax \end{bmatrix} - \begin{bmatrix} intermediate \\ input\ cost \\ per\ activity \\ unit \end{bmatrix}$	$a \in A$	Value-added Price

Production and commodity block

8	$QA_a = ad_a \cdot \left(\sum_{f \in F} \delta^a_{f\,a} \cdot QF_{f\,a}^{-\rho^a_a} \right)^{-\frac{1}{\rho^a_a}}$ $\begin{bmatrix} activity \\ level \end{bmatrix} = CES \begin{bmatrix} factor \\ inputs \end{bmatrix}$	$a \in A$	Activity Production function
9	$W_f \cdot \overline{WFDIST}_{fa} = PVA_a \cdot ad_a \cdot \left(\sum_{f \in F} \delta^a_{fa} \cdot QF_{fa}^{-\rho^a_a} \right)^{-\frac{1}{\rho^a_a} - 1} \cdot \delta^a_{fa} \cdot QF_{fa}^{-\rho^a_a}$ $\begin{bmatrix} marginal\ cost \\ of\ factor\ f \\ in\ activity\ a \end{bmatrix} = \begin{bmatrix} marginal\ revenue \\ product\ of\ factor \\ f\ in\ activity\ a \end{bmatrix}$	$a \in A$ $f \in F$	Factor Demand
10	$QINT_{c\,a} = ica_{c\,a} \cdot QA_a$ $\begin{bmatrix} intermediate \\ demand \end{bmatrix} = f \begin{bmatrix} activity \\ level \end{bmatrix}$	$a \in A$ $c \in C$	Intermediate Demand
11	$QXAC_{a\,c} = \theta_{a\,c} \cdot QA_a$ $\begin{bmatrix} \text{activity-specific} \\ \text{production of} \\ \text{commodity c} \end{bmatrix} = f \begin{bmatrix} activity \\ level \end{bmatrix}$	$a \in A$ $c \in CX$	Output Function
12	$QX_c = aac_c \cdot \left(\sum_{a \in A} \delta^{ac}_{a\,c} \cdot QXAC_{a\,c}^{-\rho^{ac}_c} \right)^{-\frac{1}{\rho^{ac}_c - 1}}$ $\begin{bmatrix} aggregate \\ production\ of \\ commodity\ c \end{bmatrix} = CES \begin{bmatrix} activity\text{-}specific \\ production\ of \\ commodity\ c \end{bmatrix}$	$c \in CX$	Output Aggregation Function

Table A.1: Mathematical summary statement for the Malawi CGE model

13	$PXAC_{a\,c} = PX_c \cdot aac_c \cdot \left(\sum_{a \in A} \delta^{ac}_{a\,c} \cdot QXAC^{-\rho^{ac}_c}_{a\,c} \right)^{-\frac{1}{\rho^{ac}_c}-1} \cdot \delta^{ac}_{a\,c} \cdot QXAC^{-\rho^{ac}_c-1}_{a\,c}$ $\begin{bmatrix} \text{marginal cost of} \\ \text{commodity } c \\ \text{from activity } a \end{bmatrix} = \begin{bmatrix} \text{marginal revenue} \\ \text{product of} \\ \text{commodity } c \\ \text{from activity } a \end{bmatrix}$	$a \in A$ $c \in C$	First-Order Condition for Output Aggregation Function
14	$QQ_c = aq_c \left(\delta^q_c \cdot QM_c^{-\rho^q_c} + (1-\delta^q_c) \cdot QD_c^{-\rho^q_c} \right)^{-\frac{1}{\rho^q_c}}$ $\begin{bmatrix} \text{composite} \\ \text{supply} \end{bmatrix} = f \begin{bmatrix} \text{import quantity, domestic} \\ \text{use of domestic output} \end{bmatrix}$	$c \in CMX$	Composite Supply (Armington) Function
15	$\frac{QM_c}{QD_c} = \left(\frac{PDD_c}{PM_c} \cdot \frac{\delta^q_c}{1-\delta^q_c} \right)^{\frac{1}{1+\rho^q_c}}$ $\begin{bmatrix} \text{import} - \\ \text{domestic} \\ \text{demand ratio} \end{bmatrix} = f \begin{bmatrix} \text{domestic} - \\ \text{import} \\ \text{price ratio} \end{bmatrix}$	$c \in CMX$	Import-Domestic Demand Ratio
16	$QQ_c = QD_c$ $\begin{bmatrix} \text{composite} \\ \text{supply} \end{bmatrix} = \begin{bmatrix} \text{domestic use of} \\ \text{domestic output} \end{bmatrix}$	$c \in CNM$	Composite Supply for Non-Imported Commodities
17	$QQ_c = QM_c$ $\begin{bmatrix} \text{composite} \\ \text{supply} \end{bmatrix} = \begin{bmatrix} \text{imports} \end{bmatrix}$	$c \in CMNX$	Composite Supply for Non-Produced Imports
18	$QX_c = at_c \cdot \left(\delta^t_c \cdot QE_c^{\rho^t_c} + (1-\delta^t_c) \cdot QD_c^{\rho^t_c} \right)^{\frac{1}{\rho^t_c}}$ $\begin{bmatrix} \text{domestic} \\ \text{output} \end{bmatrix} = CET \begin{bmatrix} \text{export quantity, domestic} \\ \text{use of domestic output} \end{bmatrix}$	$c \in CE$	Output Transformation (CET) Function
19	$\frac{QE_c}{QD_c} = \left(\frac{PE_c}{PDS_c} \cdot \frac{1-\delta^t_c}{\delta^t_c} \right)^{\frac{1}{\rho^t_c-1}}$ $\begin{bmatrix} \text{export-} \\ \text{domestic} \\ \text{supply ratio} \end{bmatrix} = f \begin{bmatrix} \text{export-} \\ \text{domestic} \\ \text{price ratio} \end{bmatrix}$	$c \in CE$	Export-Domestic Supply Ratio
20	$QX_c = QD_c$ $\begin{bmatrix} \text{domestic} \\ \text{output} \end{bmatrix} = \begin{bmatrix} \text{domestic sales of} \\ \text{domestic output} \end{bmatrix}$	$c \in CNE$	Output Transformation for Non-Exported Commodities

Table A.1: Mathematical summary statement for the Malawi CGE model

21	$$QT_c = \sum_{c' \in C'} \left(icm_{c\,c'} \cdot QM_{c'} + ice_{c\,c'} \cdot QE_{c'} + icd_{c\,c'} \cdot QD_{c'} \right)$$ $$\begin{bmatrix} \textit{demand} \\ \textit{for trade} \\ \textit{inputs} \end{bmatrix} = \begin{bmatrix} \textit{sum of trade} \\ \textit{inputs demanded for} \\ \textit{imports, exports, and} \\ \textit{domestic sales} \end{bmatrix}$$	$c \in CT$	Demand for Trade Inputs

Institution block

22	$$YF_{i\,f} = shry_{i\,f} \cdot \left(1 - \overline{TY}_f\right) \cdot \sum_{a \in A} WF_f \cdot \overline{WFDIST}_{f\,a} \cdot QF_{f\,a}$$ $$\begin{bmatrix} \textit{income of} \\ \textit{institution } i \\ \textit{from factor } f \end{bmatrix} = \begin{bmatrix} \textit{share of income} \\ \textit{of factor } f \textit{ to} \\ \textit{institution } i \end{bmatrix} \cdot \begin{bmatrix} \textit{income of factor } f \\ \textit{(net of tax)} \end{bmatrix}$$	$i \in ID$ $f \in F$	Factor Income
23	$$YI_i = \sum_{f \in F} YF_{i\,f} + \sum_{i' \in IDNG'} TR_{i\,i'} + \overline{tr}_{i\,gov} + EXR \cdot \overline{tr}_{i\,row}$$ $$\begin{bmatrix} \textit{income of} \\ \textit{institution } i \end{bmatrix} = \begin{bmatrix} \textit{factor} \\ \textit{income} \end{bmatrix} + \begin{bmatrix} \textit{transfers} \\ \textit{from other} \\ \textit{institutions} \end{bmatrix} + \begin{bmatrix} \textit{government} \\ \textit{transfers} \end{bmatrix} + \begin{bmatrix} \textit{transfers} \\ \textit{from RoW} \end{bmatrix}$$	$i \in IDNG$	Institution Income
24	$$TR_{i\,i'} = shrtr_{i\,i'} \cdot (1 - MPS_{i'}) \cdot (1 - \overline{TY}_{i'}) \cdot \left(YI_{i'} - EXR \cdot \overline{tr}_{row\,i'} \right)$$ $$\begin{bmatrix} \textit{transfer from} \\ \textit{institution } i' \textit{ to } i \end{bmatrix} = \begin{bmatrix} \textit{share of income} \\ \textit{of institution } i' \\ \textit{transfered to } i \end{bmatrix} \cdot \begin{bmatrix} \textit{income of institution } i' \\ \textit{net of savings, direct taxes,} \\ \textit{and transfers to RoW} \end{bmatrix}$$	$i \in ID$ $i' \in IDNG$	Intra-Institutional Transfers
25	$$EH_h = \left(1 - \sum_{i \in ID} shrtr_{i\,h} \right) \cdot \left(1 - MPS_h\right) \cdot (1 - \overline{TY}_h) \cdot \left(YI_h - EXR \cdot \overline{tr}_{row\,h} \right)$$ $$\begin{bmatrix} \textit{household disposable} \\ \textit{income (for consumption)} \end{bmatrix} = \begin{bmatrix} \textit{household income} \\ \textit{net of savings, direct taxes,} \\ \textit{and transfers to RoW} \\ \textit{and other institutions} \end{bmatrix}$$	$h \in H$	Household Consumption Expenditures
26	$$QH_{c\,h} = \gamma_{c\,h} + \frac{\beta_{c\,h} \cdot \left(EH_h - \sum_{c \in C} PQ_c \cdot \gamma_{c\,h} \right)}{PQ_c}$$ $$\begin{bmatrix} \textit{quantity of} \\ \textit{household demand} \\ \textit{for commodity } c \end{bmatrix} = f \begin{bmatrix} \textit{household} \\ \textit{disposable} \\ \textit{income, price} \end{bmatrix}$$	$c \in C$ $h \in H$	Household Consumption Demand
27	$$QINV_c = \overline{qinv}_c \cdot \overline{IADJ}$$ $$\begin{bmatrix} \textit{private investment} \\ \textit{demand for} \\ \textit{commodity } c \end{bmatrix} = \begin{bmatrix} \textit{base-year private} \\ \textit{investment times} \\ \textit{adjustment factor} \end{bmatrix}$$	$c \in C$	Private Investment Demand

Table A.1: Mathematical summary statement for the Malawi CGE model

28	$QG_c = \overline{qg}_c \cdot \overline{GADJ}$ $\begin{bmatrix} \text{government} \\ \text{consumption} \\ \text{demand for} \\ \text{commodity } c \end{bmatrix} = \begin{bmatrix} \text{base-year government} \\ \text{consumption} \\ \text{times} \\ \text{adjustment factor} \end{bmatrix}$	$c \in C$	Government Consumption Demand
29	$YG = \sum_{f \in F} YF_{gov\, f} + \sum_{i \in I} \overline{TY}_i \cdot YI_i + \sum_{i \in IDNG} TR_{gov\, i} \cdot YI_i + EXR \cdot \overline{tr}_{gov\, row}$ $+ \sum_{f \in F} \overline{TY}_f \cdot \sum_{a \in A} WF_f \cdot \overline{WFDIST}_{fa} \cdot QF_{fa}$ $+ \sum_{c \in C} tq_c \left(PDD_c \cdot QD_c + PM_c QM_c \right) + \sum_{a \in A} ta_a \cdot PA_a \cdot QA_a$ $+ \sum_{c \in C} tm_c \cdot EXR \cdot pwm_c \cdot QM_c + \sum_{c \in C} te_c \cdot EXR \cdot pwe_c \cdot QE_c$ $\begin{bmatrix} \text{government} \\ \text{revenue} \end{bmatrix} = \begin{bmatrix} \text{factor} \\ \text{income} \end{bmatrix} + \begin{bmatrix} \text{direct taxes} \\ \text{from} \\ \text{institutions} \end{bmatrix} + \begin{bmatrix} \text{transfers from} \\ \text{domestic} \\ \text{institutions} \end{bmatrix} + \begin{bmatrix} \text{transfers} \\ \text{from} \\ \text{RoW} \end{bmatrix}$ $+ \begin{bmatrix} \text{direct taxes} \\ \text{from factors} \end{bmatrix} + \begin{bmatrix} \text{sales} \\ \text{tax} \end{bmatrix} + \begin{bmatrix} \text{activity} \\ \text{tax} \end{bmatrix} + \begin{bmatrix} \text{import} \\ \text{tariffs} \end{bmatrix} + \begin{bmatrix} \text{export} \\ \text{taxes} \end{bmatrix}$		Government Revenue
30	$EG = \sum_{c \in C} PQ_c \cdot QG_c + \sum_{i \in IDNG} \overline{tr}_{i\, gov} + EXR \cdot \overline{tr}_{row\, gov}$ $\begin{bmatrix} \text{government} \\ \text{spending} \end{bmatrix} = \begin{bmatrix} \text{government} \\ \text{consumption} \end{bmatrix} + \begin{bmatrix} \text{transfers to} \\ \text{domestic} \\ \text{institutions} \end{bmatrix} + \begin{bmatrix} \text{transfers} \\ \text{to RoW} \end{bmatrix}$		Government Expenditures
31	$GSAV = YG - EG$ $\begin{bmatrix} \text{government} \\ \text{savings} \end{bmatrix} = \begin{bmatrix} \text{government} \\ \text{revenue} \end{bmatrix} - \begin{bmatrix} \text{government} \\ \text{expenditures} \end{bmatrix}$		Government Savings

System Constraint Block

32	$\sum_{a \in A} QF_{f\, a} = \overline{QFS}_f$ $\begin{bmatrix} \text{demand for} \\ \text{factor } f \end{bmatrix} = \begin{bmatrix} \text{supply of} \\ \text{factor } f \end{bmatrix}$	$f \in F$	Factor Market
33	$QQ_c = \sum_{a \in A} QINT_{c\, a} + \sum_{h \in H} QH_{c\, h} + QG_c + QT_c$ $+ QINV_c + qginv_c + qdst_c$ $\begin{bmatrix} \text{composite} \\ \text{supply} \end{bmatrix} = \begin{bmatrix} \text{intermediate} \\ \text{use} \end{bmatrix} + \begin{bmatrix} \text{household} \\ \text{consumption} \end{bmatrix} + \begin{bmatrix} \text{government} \\ \text{consumption} \end{bmatrix} + \begin{bmatrix} \text{trade} \\ \text{input use} \end{bmatrix}$ $+ \begin{bmatrix} \text{private} \\ \text{investment} \end{bmatrix} + \begin{bmatrix} \text{government} \\ \text{investment} \end{bmatrix} + \begin{bmatrix} \text{stock} \\ \text{change} \end{bmatrix}$	$c \in C$	Composite Commodity Markets

Table A.1: Mathematical summary statement for the Malawi CGE model

34	$$\sum_{c \in C} pwm_c \cdot QM_c + \sum_{i \in ID} \overline{tr}_{row\ i} = \sum_{c \in C} pwe_c \cdot QE_c + \sum_{i \in ID} \overline{tr}_{i\ row} + \overline{FSAV}$$ $$\begin{bmatrix} import \\ spending \end{bmatrix} + \begin{bmatrix} transfers \\ to\ RoW \end{bmatrix} = \begin{bmatrix} export \\ revenue \end{bmatrix} + \begin{bmatrix} transfers \\ from\ RoW \end{bmatrix} + \begin{bmatrix} foreign \\ savings \end{bmatrix}$$		Current Account Balance for RoW (in Foreign Currency)
35	$$\sum_{c \in C} PQ_c \cdot QINV_c + \sum_{c \in C} PQ_c \cdot qdst_c + \sum_{c \in C} PQ_c \cdot qginv_c$$ $$= \sum_{i \in IDNG} MPS_i \cdot \left(1 - \overline{TY}_i\right) \cdot \left(YI_i - EXR \cdot \overline{tr}_{row\ i}\right) + GSAV + EXR \cdot \overline{FSAV}$$ $$\begin{bmatrix} private \\ investment \end{bmatrix} + \begin{bmatrix} stock \\ change \end{bmatrix} + \begin{bmatrix} government \\ investment \end{bmatrix} = \begin{bmatrix} non\text{-}govern\text{-} \\ ment\ savings \end{bmatrix} + \begin{bmatrix} government \\ savings \end{bmatrix} + \begin{bmatrix} foreign \\ savings \end{bmatrix}$$		Savings-Investment Balance
36	$$\sum_{c \in C} PQ_c \cdot cwts_c = cpi$$ $$\begin{bmatrix} price\ times \\ weights \end{bmatrix} = \begin{bmatrix} CPI \end{bmatrix}$$		Price Normalization
37	$$TABS = \sum_{h \in H} \sum_{c \in C} PQ_c \cdot QH_{c\ h} + \sum_{c \in C} PQ_c \cdot QG_c + \sum_{c \in C} PQ_c \cdot QINV_c$$ $$+ \sum_{c \in C} PQ_c \cdot qdst_c + \sum_{c \in C} PQ_c \cdot qginv_c$$ $$\begin{bmatrix} total \\ absorption \end{bmatrix} = \begin{bmatrix} household \\ consumption \end{bmatrix} + \begin{bmatrix} government \\ consumption \end{bmatrix} + \begin{bmatrix} private \\ investment \end{bmatrix} + \begin{bmatrix} stock \\ change \end{bmatrix} + \begin{bmatrix} government \\ investment \end{bmatrix}$$		Total Absorption
38	$$INVSHR \cdot TABS = \sum_{c \in C} PQ_c \cdot QINV_c + \sum_{c \in C} PQ_c \cdot qginv_c + \sum_{c \in C} PQ_c \cdot qdst_c$$ $$\begin{bmatrix} investment\text{-} \\ absorption \\ ratio \end{bmatrix} \cdot \begin{bmatrix} total \\ absorption \end{bmatrix} = \begin{bmatrix} private \\ investment \end{bmatrix} + \begin{bmatrix} government \\ investment \end{bmatrix} + \begin{bmatrix} stock \\ change \end{bmatrix}$$		Ratio of Investment to Absorption
39	$$GOVSHR \cdot TABS = \sum_{c \in C} PQ_c \cdot QG_c$$ $$\begin{bmatrix} government \\ consumption\text{-} \\ absorption \\ ratio \end{bmatrix} \cdot \begin{bmatrix} total \\ absorption \end{bmatrix} = \begin{bmatrix} government \\ consumption \end{bmatrix}$$		Ratio of Government Consumption to Absorption

Note: *The mathematical statement is simplified in that it does not include domain controls for variables.

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