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A STATIC COMPUTABLE GENERAL EQUILIBRIUM MODEL OF AGRICULTURAL AND FORESTRY REGIONAL MARKETS (AFRM)

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1 Introduction

This report provides a detailed description of a static IMPLAN SAM-based regional computable general equilibrium (CGE) model, first developed in Monge (2012), with special emphasis on the market for agricultural land in any arbitrary state-level aggregation in the U.S. The CGE model structure described in this document is a hybrid between Lofgren et al. (2002) and Bryant et al. (2011). The model is especially well-suited to analyzing economic shocks affecting land allocation between agriculture and forestry. Monge (2012) applied the model to analyze the land-use change from agriculture to forestry motivated by a forest-based carbon sequestration policy funded by the government.

In the literature, CGE models belong to a broader group of models known as sector optimization models. The alternative models belonging to this broad group are input-output (IO) and partial equilibrium (PE) models. IO models are mainly based on economic IO tables and take into account the economic linkages between different producing sectors and regions. However, when the substitution (transformation) of inputs (outputs) going (coming) into (out of) a demand (production) function is key among the objectives of any study, the assumed fixed elasticity of substitution (viz., $\sigma = 0$) by IO models makes these a less robust alternative.

Besides IO models, the second class of models applied in regional studies are PE models. PE models concentrate on specific sectors of an economy considering the other sectors exogenous to the model. Models such as FASOM and USMP have been extensively used to model land-use change among the agriculture and forestry sectors (Adams et al., 1999; Alig et al., 1997, 1998; Environmental Protection Agency (EPA)., 2005; Lewandrowski et al., 2004). The main advantage of these models is the detailed disaggregation of the sectors under scrutiny, which facilitates a policy-impact analysis. However, most PE models represent land through reduced-form supply, yield, and area response equations, and do not consider its demand side (Kretschmer and Peterson, 2010). In other words, PE models do not consider an explicit market for land and, as a result, ignore the substitutability of land, which is key to all land-use change studies. Hence, the approach that circumvents IO models' fixed-substitutability limitation and PE models' scope limitation is the CGE modeling approach.

A CGE model is essentially a set of equations that explains the optimizing behavior of the different actors in an economy through first order conditions. CGE models typically solve a set of first-order conditions derived from utility and profit optimization theory. Among the key components considered in CGE models are the flexible substitution of inputs going into a behavioral function and the explicit market of factors of production such as capital, labor and land.[1] The inputs and outputs of the production and utility functions to be maximized are reflected by the production and consumption values recorded in the Social Accounting Matrix (SAM) in a specific year. All of these transactions reflected in the SAM in a specific year are assumed to be in equilibrium.

The SAM is a record-keeping framework of the payments between economic actors in a specific economic region and its regional context (i.e. trade). The economic actors included in any generic SAM are: activities, commodities, institutions, production factors and trade. An activity represents an aggregated firm in any specific sector in the economy that consumes and produces commodities as inputs and outputs, respectively. The institutions are the households, enterprises and the government. The production factors are capital, labor and, in the case of agriculture and forestry, land. Each of these institutions receives payments for offering factors of production (households) and for offering commodities and services (enterprises). The government is modeled as a passive institution that collects taxes, receives transfers and distributes these back into the economy.

[1] CGE models also consider the flexible transformation of outputs coming from a behavioral function.

2 Data

The model reflects the sectoral and regional aggregations built and imported from IMPLAN, with activities, their respective commodities, basic factors of production (labor and capital), agricultural land as a factor of production divided into Major Land Resource Areas (MLRA), nine household categories based on income levels, six federal and state government divisions, enterprises, investment, inventory and two trade accounts: the rest of the U.S. and the rest of the world.

The SAMs used in this CGE model employ, as a primary source, data from the Impact Analysis for Planning (IMPLAN) Version 3.0, reflecting economic activity for 2008. The IMPLAN dataset contains information for 440 activity sectors at the national, state and county level. Any generic SAM reflects transactions among sectors of the economy as well as non-market transactions such as transfers to and from the government. The basic structure of an IMPLAN SAM is shown in figure 1. For a more detailed structure and the contents of every cell (transaction) please refer to MIG (1998) or figure 10 in the appendix with its respective definitions in table 4.

Any basic IMPLAN SAM contains the following value-added and institutional accounts:

- Value-added:
  - employee compensation,
  - other property income,
  - proprietary income,
  - indirect business taxes,
- Households (categories based on annual income of thousands of U.S. dollars):
  - less than 10,
  - between 10 and 15,
  - between 15 and 25,
  - between 25 and 35,
  - between 35 and 50,
  - between 50 and 75,
  - between 75 and 100,
  - between 100 and 150, and
  - more than 150,
- Government:
  - federal:
    - defense,
    - non-defense,
    - investment,
  - state and local:
    - education,
    - non-education,
    - investment,
- Enterprises (representative account),

- Investment,
- Inventory,
- Trade:
  - rest of the U.S. (for regional aggregations),
  - rest of the World (for regional and national aggregation).

		Activities	Commodities	Factors	Institutions	Trade		TOTAL
						Rest of World	Rest of US	
Activities			Domestic Commodity Output			Commodity Exports	Commodity Exports	Incomes
Commodities		Domestic Intermediate Commodity Inputs			Domestic Institutional Commodity Consumption			
Factors		Value-added						
Institutions			Domestic Institutional Commodity Production	Factor Income to Institutions	Institutional Transfers	Institutional Commodity Exports and Transfers	Institutional Commodity Exports and Transfers	
Trade	Rest of World	Commodity Imports		Factor Imports and Transfers	Institutional Commodity Imports and Transfers	Trans-shipments		Imports
	Rest of US	Commodity Imports		Factor Imports and Transfers	Institutional Commodity Imports and Transfers			
TOTAL		Expenditures				Exports		

Figure 1: Basic structure of an IMPLAM SAM

2.1 Value-added decomposition

Monge (2012) developed a procedure to accommodate the IMPLAN ambiguous value-added categories into the more conventionally used production factor accounts of labor, capital and land. In Koh (1991), employee compensation, proprietary income and other property income were considered the equivalents of labor, capital and land returns, respectively. However, according to Marcouiller et al. (1993) and Vargas et al. (2010), this decomposition method underestimates capital returns and overestimates labor returns since proprietary income is defined as income from self employment. In other words, proprietary income includes a share of both capital and labor returns.

As explained in Monge (2012), this CGE model considers employee compensation and other property income part of labor and capital returns, respectively, as depicted in figure 2. A methodology was developed to partition proprietary income into labor and capital returns. Land, is treated differently since IMPLAN reports payments to land as the intermediate use of a real estate commodity by different activities (Olson, 2011a). Hence, land rents were a composition of this real estate commodity demand and a share of the modified capital account as depicted in figure 2.

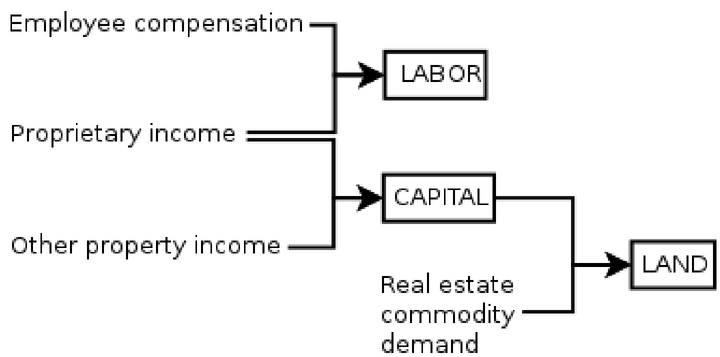

Figure 2: IMPLAN factors decomposition into the more intuitive accounts of factors of production

The indirect business taxes (IBT) account, now termed “taxes on production and import less subsidies” by NIPA, is a combination of excise, sales and property taxes plus other non-tax charges such as fees, fines, licenses and permits. All these categories are aggregated by IMPLAN into a single value for each production activity. This IBT aggregation per activity poses two problems when using the SAM for CGE modeling purposes:

1. when considering the Armington convention of imperfect substitutability between imports and domestic supply, import duties should be reflected in the SAM as payments from the commodity accounts, not activities, to an import duty account, and

2. since IMPLAN data are based on the input-output tables published by the Bureau of Economic Analysis (BEA), Dixon and Maureen (2001) and Giesecke (2009) have stated that IMPLAN data replicates the misallocation of sales taxes where these taxes are attributed to the activities collecting them and not to the activities producing the commodities on which the taxes are imposed. The collecting activities are the retail and wholesale trade activities.

Hence, to accommodate the IMPLAN IBT account to the conventional tax accounts for CGE modeling (import, sales, factor-use and production taxes), the IMPLAN SAM was modified to include them as explained in Monge (2012). Import duties were estimated by commodity and disaggregated from the aggregate IBT payment by activity. Furthermore, sales taxes were redistributed from the collecting activities to the appropriate producing activities.

2.2 Aggregation of activities and regions

There are two possible types of aggregation implicit in a basic IMPLAN SAM:

Activity and commodity aggregation: since some of the 440 activities and commodities share common aspects,[2] these could be aggregated into representative activities and commodities.

[2]Such as technology, inputs, outputs, regional location, etc.

For example, Monge (2012) considered 32 representative activities and commodities as shown in table 1. Due to the main objective of the study, all the activities and commodities related to agriculture and forestry were left at their original IMPLAN disaggregation levels.[3] The crops included in the oilseed, grain, tobacco, cotton, sugar and all other crop farming are listed in table 3 in the appendix.[4] The notation used for aggregate activities and commodities is as follows:

$$implan \supseteq \begin{cases} a \\ c \end{cases}, \tag{1}$$

where a and c are the sets of the 32 aggregated activities and commodities, respectively; and $implan$ is the set of the 440 activities and commodities.

Table 1: Aggregation of IMPLAN Activities and Commodities in Monge (2012)

Aggregated activities and commodities	Activities		Commodities	
	Abbrev.	IMPLAN codes	Abbrev.	IMPLAN codes
1 - Oilseed farming	Aolsd	1	Colsd	3001
2 - Grain farming	Agran	2	Cgran	3002
3 - Tobacco farming	Atobc	7	Ctobc	3007
4 - Cotton farming	Acott	8	Ccott	3008
5 - Sugarcane and sugar beet farming	Asugr	9	Csugr	3009
6 - All other crop farming	Aocrp	10	Cocrp	3010
7 - Cattle ranching and farming	Acatt	11	Ccatt	3011
8 - Dairy cattle and milk production	Adair	12	Cdair	3012
9 - Logging	Alogg	16	Clogg	3016
10 - Other agriculture	Aoagr	3-6,13-15,17-19	Coagr	3003-3006,3013-3015,3017-3019
11 - Mining	Amini	20-30	Cmini	3020-3030
12 - Utilities	Autil	31-33	Cutil	3031-3033
13 - Construction	Acons	34-40	Ccons	3034-3040
14 - Manufacturing	Amanf	41-318	Cmanf	3041-3318
15 - Wholesale trade	Awhol	319	Cwhol	3319
16 - Retail trade	Aretl	320-331	Cretl	3320-3331
17 - Transportation and warehousing	Atrns	332-340	Ctrns	3332-3340
18 - Information	Ainfo	341-353	Cinfo	3341-3353
19 - Financial services	Afinc	354-359	Cfinc	3354-3359
20 - Real estate	Aland	360	Cland	3360
21 - Other property rent	Aornt	361-366	Cornt	3361-3366
22 - Professional, scientific and technical services	Aprof	367-380	Cprof	3367-3380
23 - Management of companies and enterprises	Amgmt	381	Cmgmt	3381
24 - Administrative and waste services	Aadmw	382-390	Cadmw	3382-3390
25 - Education services	Aeduc	391-393	Ceduc	3391-3393
26 - Health services	Ahlth	394-401	Chlth	3394-3401
27 - Amusement and recreational services	Aentt	402-410	Centt	3402-3410
28 - Accomodation and food services	Ahotl	411-413	Chotl	3411-3413
29 - Other services	Aoser	414-426	Coser	3414-3426
30 - Government utilities and enterprises	Agven	427-432	Cgven	3427-3432
31 - Unclassified	Auncl	433-436	Cuncl	3433-3436
32 - Government employment and payroll	Agvem	437-440	Cgvem	3437-3440

[3] Only the "other agriculture" sector is composed of many other IMPLAN sectors such as vegetable and melon (IMPLAN code 3); fruit (4); tree nut (5); greenhouse, nursery, and floriculture (6); poultry and egg (13); animal production, except cattle, poultry and eggs (14); forest nurseries, forest products, and timber tracts (15); fishing (17); hunting and trapping (18); and support activities for agriculture and forestry (19).

[4] For a more detailed list of the IMPLAN sectors, visit: http://implan.com.

Regional aggregation: Monge (2012) developed a method for rapidly constructing a SAM for regions consisting of subsets of U.S. states (including the possibility of all states). By developing a method for constructing a SAM, rather than a single SAM, an aggregation scheme appropriate for a particular analysis can be rapidly implemented. For example, Monge (2012) used the Eastern half of the U.S. to assess the potential to convert great agricultural land extensions to forest motivated by carbon sequestration policies as presented in figure 3. The notation used for regional aggregations is as follows:

$$region \subseteq states, \tag{2}$$

where *region* is a set representing the regional aggregation and *states* is a set containing the 48 states included in the contiguous U.S.

2.3 Land heterogeneity

Besides a detailed disaggregation of land uses across the U.S., a proper recognition of land heterogeneity plays a key role in the adequate allocation of land among competing uses. The USDA developed a classification of geographically associated land units called Major Land Resource Areas (MLRA) as shown in figure 4. A complete list, description and location of each MLRA can be found in Natural Resources Conservation Services (NRCS) (2006). There are 278 MLRAs identified by Arabic numbers and a descriptive geographic name. The main criteria used by NRCS to categorize land into the different MLRAs are: physiographic, geological, climatic, water, soil, biological and land use characteristics.

The percentages of land covered by each MLRA at the county level were obtained by superimposing two maps (counties and MLRAs) based on Geographic Information System (GIS) data provided by NRCS (2011). Each county was assigned to the predominant MLRA:

$$l \cong county, \tag{3}$$

where l is the land set representing the different MLRAs. Using this mapping, the county-level land rents developed in Monge (2012) were aggregated to obtain a matrix containing total land rents payments to each MLRA in each state as shown in figure 5.

The final modified IMPLAN SAM used as an input for the CGE model is shown in figure 11 in the appendix with its respective definitions in table 5.

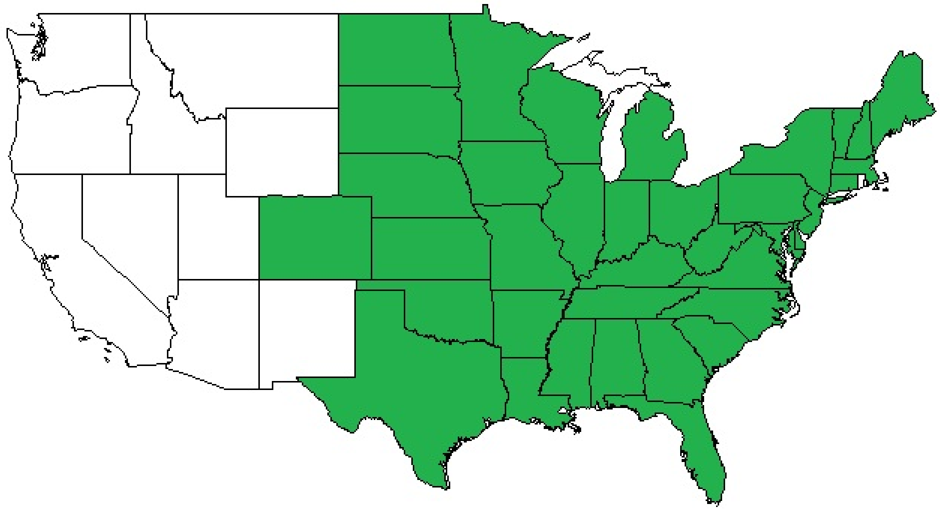

Figure 3: Regional aggregation (in green color) considered for the analysis of the impacts of a forest-based carbon sequestration program on land-use change

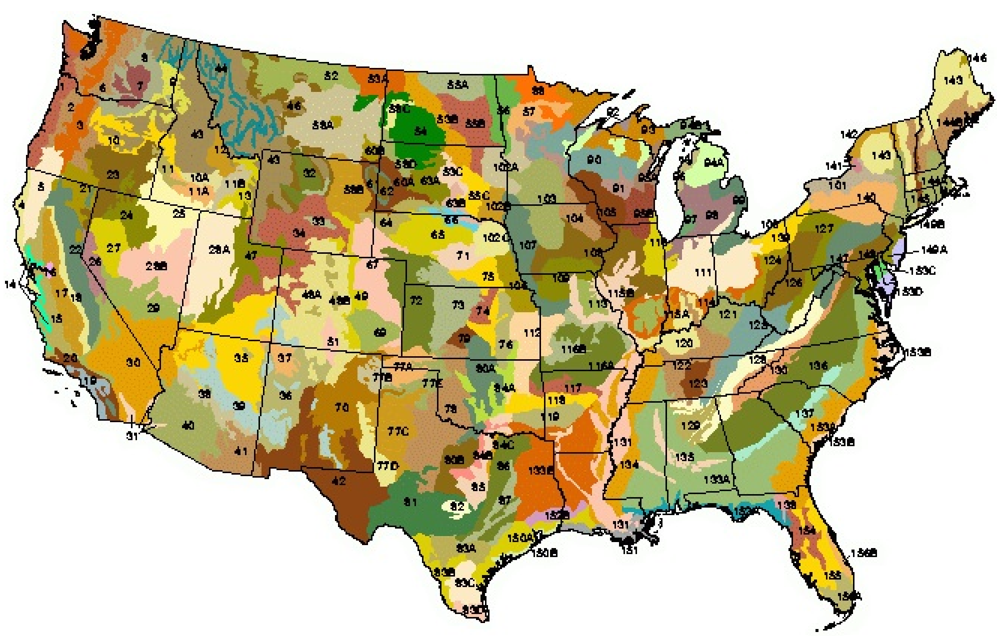

Figure 4: Major Land Resource Areas (MLRA) in the conterminous U.S. (Source: NRCS)

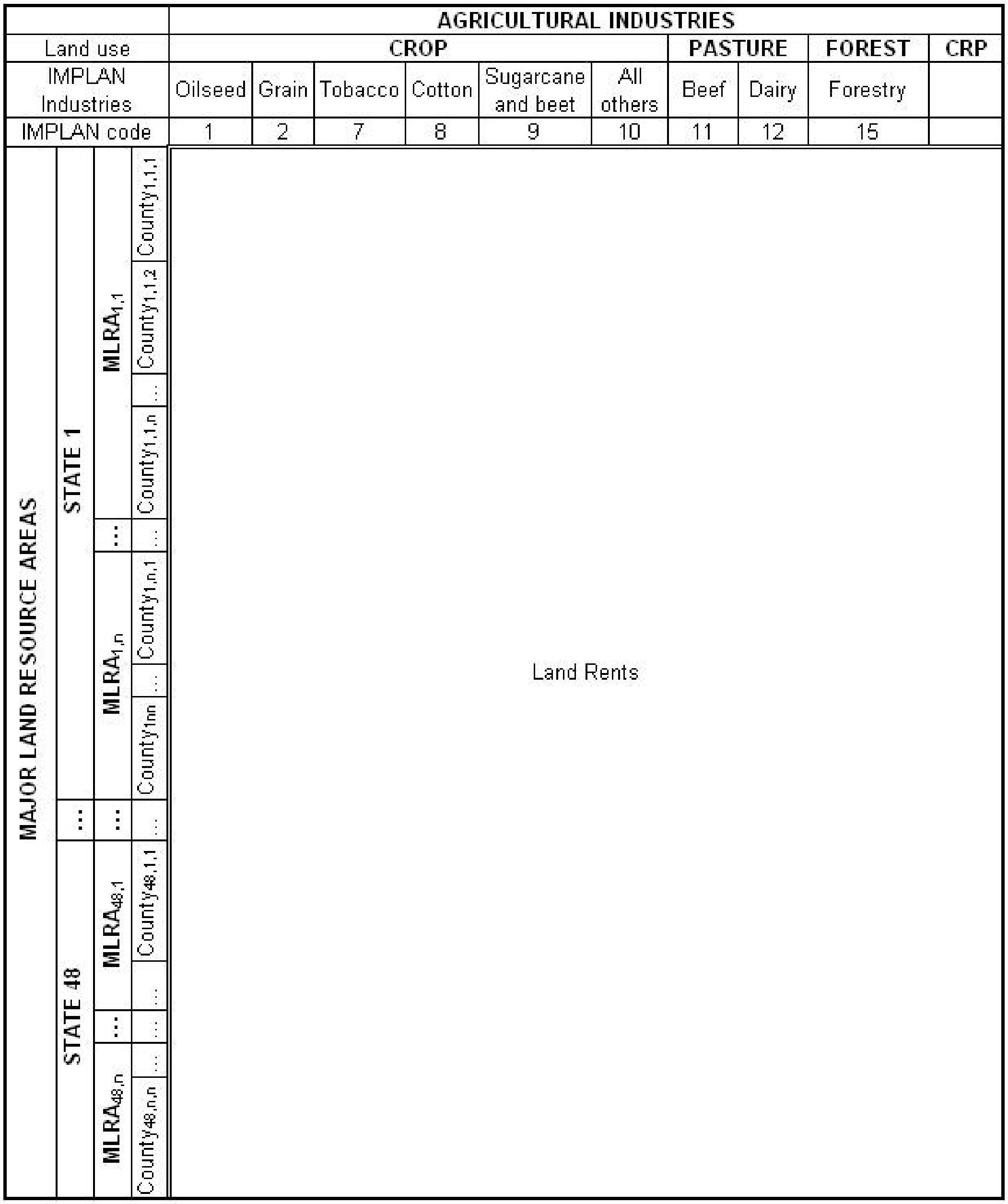

Figure 5: Land rent matrix obtained as the final result of assigning estimated land rents for different land-use types to the Major Land Resource Areas (MLRAS)

3 Model

Model code was initially adapted from the model by Bryant et al. (2011). It relies on a nesting structure based on constant returns to scale, nested constant elasticity of substitution (CES) functions to emulate production, consumption and aggregation behavior. The code is structured such that the CES function used in the model encompasses the two generally-used-by-convention limiting cases: Leontief and Cobb-Douglas. The exogenously-set substitution elasticities (σ) required as inputs for the CES functions are the determining factors between the two limiting cases for every producing and consuming entity, and aggregation scheme. The rest of the parameters that go into the CES function are endogenously estimated and calibrated against the exogenous substitution elasticities and the base year prices, quantities and tax rates reflected in the SAM. Prices in the base year are assumed to be unity; hence, the units of measurement of factors and commodities are inferred from the SAM. Land, as a factor of production, is the exception since land prices and quantities reflect per-acre rents (not unity) and acreage (not SAM values), respectively. As Bryant et al. (2011) states, the model follows a bottom-top routine meaning that the model calibrates first bottom nests and top nests afterwards.[5]

Since there is no explicit objective function to optimize, this type of model relies on a set of first order conditions to maximize utilities (consumption side) and profits (production side) subject to a full-budget-allocation and a zero-profit condition, respectively. Hence, the model conforms to a mixed complementarity optimization problem. The heart of the model is a set of excess supply functions describing a Walrasian market equilibrium. Hence, all market clearances (factors, domestic and foreign commodities) are modeled through these excess supply functions and their respective prices. Equations preserving accounting identities among institutions and imposing model closures follow a similar structure as the one shown in Lofgren et al. (2002).

The source code for the model has been written in the General Algebraic Modeling System (GAMS) (Brooke et al., 1998). Since the model is structured following a mixed complementarity problem, the solver used is PATH (Ferris and Munson, 2000). The notation used to represent a complementarity relationship is the following one:

$$QS - QD \geq 0 \perp P \geq 0 \tag{4}$$

where for any arbitrary commodity or factor, QS is the quantity supplied, QD is the quantity demanded, P is its price and the $\perp$ symbol denotes a complementarity relationship. The inequality to the left of the $\perp$ symbol is the excess supply relationship. This notation implies that either the excess supply or the price is exactly zero, and the other is strictly greater than zero. For example, the first case would hold when $P = 0$ and $QS - QD > 0$. The second case would hold when $P > 0$ and $QS - QD = 0$.

The basic CGE model structure can be divided into four major parts:

1. Activities, production and factor markets,
2. Institutions,
3. Commodity markets, and
4. Macroeconomic balances.

The notational convention followed is similar to Lofgren et al. (2002) and explained in table 2. The parameters used in the following equations and reflecting base-year SAM relationships are detailed in table 6 in the appendix. SAM represents base-year SAM transactions. Also in the appendix, figure 12 and its respective formulas in table 7 are provided to facilitate the interpretation and relate the SAM to the mathematical model.

[5]As will be explained later, for the land markets, the constant elasticity of transformation (CET) specification is used to reflect the perfect- and imperfect-transformability limiting cases for each land category (MLRA).

Table 2: Notational Structure

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
Commodity and factor quantities	Q or q
Commodity and factor pices	P
Nests' input quantities	QX
Nests' output quantities	QY
Nests' input prices	PX
Nests' output prices	PY
Substitution and transformation elasticities	σ with respective nest as subscript
Shares	Start with sh, followed by source and ending with receiving entity. All shares are fixed to the base-year
Transfer parameter	Start with $trns$, followed by source and ending with receiving entity
Transfer variable	Start with receiving entity and end with $TRNS$
Taxes	Start with t

4 Activities, production and factor markets

As shown in figure 6, the basic CGE model reflects production activities (a) as a set of top nests (*ActTop*) that use as inputs the bundles produced by an intermediate input nest (*ActInt*), a land nest for agricultural activities (*ActLand*) and a value-added nest reflecting the demand of primary factors (*ActVad*). To reflect a certain degree of substitutability among input commodities and factors, the elasticities of substitution used by default are: 0.5 for σ_{ActTop}, 0.5 for σ_{ActInt}, 0.45 for σ_{ActVad} and 0.5 for $\sigma_{ActLand}$. For the commercial logging activity, we follow Monge (2012) and use a σ_{ActTop} of 0.2 to reflect a more accurate ratio between acreage used by the activity and carbon offset generation.

The *ActLand* nest includes a different specification than the rest of the nests where quantities are taken directly from the SAM and prices are unity. The *ActLand* nest includes the estimated per-acre rents ($RENTACRE$) as prices and acreage demanded by the different activities ($ACRES$) as quantities. Total rents ($RENT$) is the product of the per-acre price paid by the activities using land and the acreage demanded.

The model is structured such that it accommodates the possibility of activities producing more than one output. Hence it includes a joint production nest (*JntPrd*). This specification was employed by Monge (2012) to model carbon offsets generated by the existing commercial logging activity. A zero elasticity of transformation is used by default for this nest to reflect a constant-proportion production regime.

Each activity is assumed to maximize profits, which are defined as the revenues produced by selling different commodities at producer's prices minus the costs of factors, land and intermediate inputs at factors and consumer's prices, respectively.

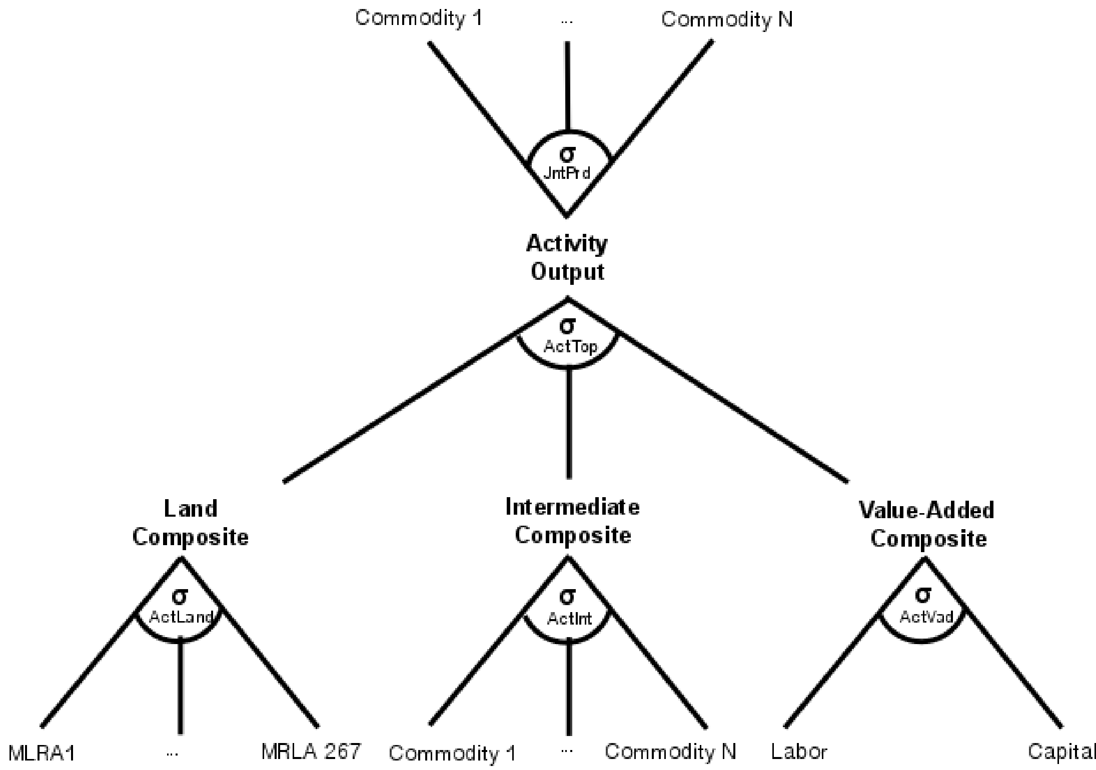

Figure 6: Representation of production activities in the CGE model

Factors of production (f) are assumed immobile between the region under study and outside regions. However, they are assumed to be mobile across activities. Hence, the model generates long-run equilibria under the different parametric shocks. Land (l) mobility across agricultural activities will be explained below. The endowments of each primary factor (qf) and land category (MLRA) (ql) are fixed and taken directly from the base-year SAM as shown in equations (5) and (6), respectively:

$$qf_f \geq \sum_a QXActVad_{a,f} \perp PF_f, \tag{5}$$

$$ql_l \geq QYLandBot_l \perp PL_l. \tag{6}$$

Estimated factor prices (or wage) and land rents are assumed to be the same across activities for each factor and MLRA, respectively. Each estimated factor price and land rent vary to ensure factor and land market clearance. Factor income after taxes and depreciation (in the case of capital) and land rents (according to Olson (2011b)) are distributed among the different households and a single representative enterprise.

5 Land markets

Similar to Bryant et al. (2011), land markets have been modeled following Hertel et al. (2010); Darwin et al. (1995); Ahammad and Mi (2005); and Ahmed et al. (2008) where land supply is determined by a constant elasticity of transformation (CET) revenue function.[6] To reflect land

[6]The only difference in the specification of a CES and a CET function is the sign of σ. A positive sign implies a CES function, a negative sign a CET function.

heterogeneity in the U.S., land endowments have been divided into 217 different MLRAs (l). From these endowments, land is supplied to three broad land uses (crop, pasture and forestry) and from these to all the different agricultural activities (agr). To reflect rent and transformability differences among the alternative uses, land supply has been divided into three nesting levels as depicted in figure 7:

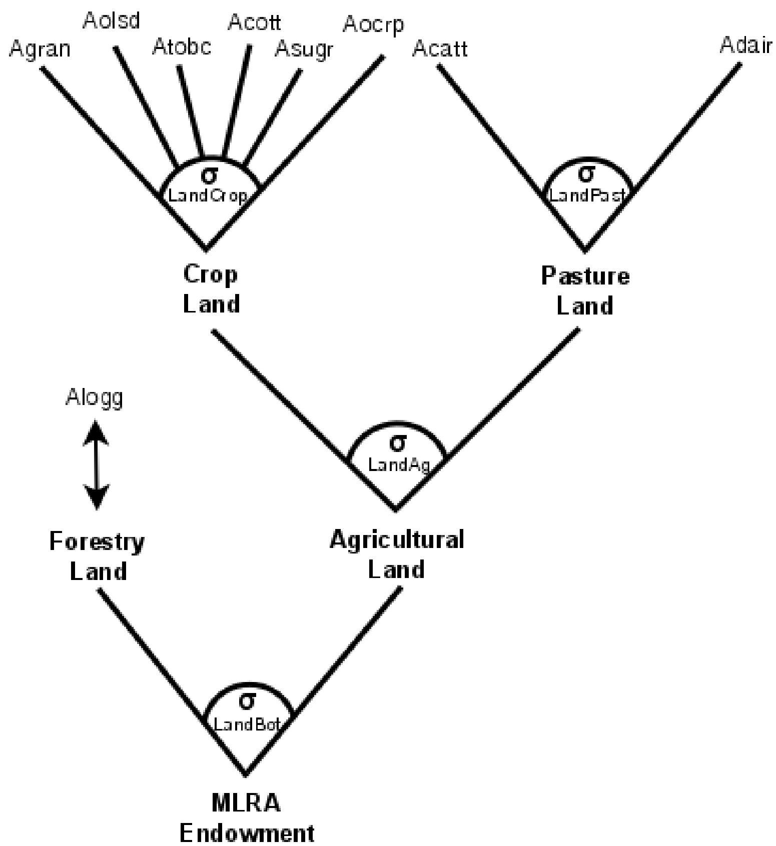

Figure 7: Representation of land markets in the CGE model

1. A nest that supplies land to forestry and agricultural land ($LandBot$) as formulated in equations (7) and (8), respectively. The elasticity of transformation ($\sigma_{LandBot}$) used for the majority of the MLRAs (-0.029) mirrors calibrated values in Bryant et al. (2011). The low value reflects a low degree of transformation between agricultural land (crop and pastureland) and forestry land. The elasticity of some MLRAs was lower due to the small rent payments coming from the logging activity. The starting values used for prices and quantities for each MLRA are listed in equations (9) - (13).

$$QXLandBot_{l,'ForestryLand'} \geq QXActLand_{alogg,l} \perp PLForestry_l, \tag{7}$$

$$QXLandBot_{l,'AgriculturalLand'} \geq QYLandAg_l \perp PYLandAg_l, \tag{8}$$

$$QXLandBot_{l,'ForestryLand'} = ACRES_{l,alogg}, \tag{9}$$

$$QXLandBot_{l,'AgriculturalLand'} = \sum_{acrop} ACRES_{l,acrop} + \sum_{apast} ACRES_{l,apast}, \quad (10)$$

$$PYLandBot_l = \frac{\sum_{agr} RENT_{l,agr}}{\sum_{agr} ACRES_{l,agr}}, \quad (11)$$

$$PXLandBot_{l,'ForestryLand'} = \frac{RENT_{l,alogg}}{ACRES_{l,alogg}}, \quad (12)$$

$$PXLandBot_{l,'AgriculturalLand'} = \frac{\sum_{acrop} RENT_{l,acrop} + \sum_{apast} RENT_{l,apast}}{\sum_{acrop} ACRES_{l,acrop} + \sum_{apast} ACRES_{l,apast}}, \quad (13)$$

where *acrop*, *apast* and *alogg* are sets including activities demanding cropland, pastureland and forest land, respectively. The activities included in *acrop* are grain, oilseed, tobacco, cotton, sugar cane and beets, and other crops farming. The activities included in *apast* are beef and dairy cattle farming. The activity included in *alogg* is commercial forestry.

2. A nest within agriculture that supplies land to crop- and pasture-related activities ($LandAg$) as formulated in equations (14) and (15), respectively. The elasticity of transformation (σ_{LandAg}) used for this nest (-0.709) mirrors calibrated the calibrated value by Bryant et al. (2011) and reflects a relatively high degree of transformation between crop and pastureland. The starting values used for prices and quantities for each MLRA and agricultural land use are listed in equations (16) - (20).

$$QXLandAg_{l,'CropLand'} \geq QYLandCrop_l \perp PYLandCrop_l, \quad (14)$$

$$QXLandAg_{l,'PastureLand'} \geq QYLandPast_l \perp PYLandPast_l, \quad (15)$$

$$QXLandAg_{l,'CropLand'} = \sum_{acrop} ACRES_{l,acrop}, \quad (16)$$

$$QXLandAg_{l,'PastureLand'} = \sum_{apast} ACRES_{l,apast}, \quad (17)$$

$$PYLandAg_l = PXLandBot_{l,'AgriculturalLand'}, \quad (18)$$

$$PXLandAg_{l,'CropLand'} = \frac{\sum_{acrop} RENT_{l,acrop}}{\sum_{acrop} ACRES_{l,acrop}}, \quad (19)$$

$$PXLandAg_{l,'PastureLand'} = \frac{\sum_{apast} RENT_{l,apast}}{\sum_{apast} ACRES_{l,apast}}. \quad (20)$$

3. Two nests, one within cropland ($LandCrop$) and one within ($LandPast$) pastureland, that supply land to all the agricultural activities as formulated in equations (21) - (26) for cropland and (27) - (28) for pastureland. The elasticities of transformation used by default for both nests ($\sigma_{LandCrop}$ and $\sigma_{LandPast}$) are -5 to reflect a high degree of transformation between activities using cropland and activities using pastureland. The starting values used for prices and quantities for each MLRA and activity are listed in equations (29) - (34).

$$QXLandCrop_{l,'grain'} \geq QXActLand_{acrop,l} \perp PGrainLand_l, \tag{21}$$

$$QXLandCrop_{l,'oilseed'} \geq QXActLand_{acrop,l} \perp POilseedLand_l, \tag{22}$$

$$QXLandCrop_{l,'tobacco'} \geq QXActLand_{acrop,l} \perp PTobaccoLand_l, \tag{23}$$

$$QXLandCrop_{l,'cotton'} \geq QXActLand_{acrop,l} \perp PCottonLand_l, \tag{24}$$

$$QXLandCrop_{l,'sugar'} \geq QXActLand_{acrop,l} \perp PSugarLand_l, \tag{25}$$

$$QXLandCrop_{l,'othercrop'} \geq QXActLand_{acrop,l} \perp POtherCropLand_l, \tag{26}$$

$$QXLandPast_{l,'cattle'} \geq QXActLand_{apast,l} \perp PCattleLand_l, \tag{27}$$

$$QXLandPast_{l,'dairy'} \geq QXActLand_{apast,l} \perp PDairyLand_l, \tag{28}$$

$$QXLandCrop_{l,acrop} = ACRES_{l,acrop}, \tag{29}$$

$$QXLandPast_{l,apast} = ACRES_{l,apast}, \tag{30}$$

$$PYLandCrop_l = PXLandAg_{l,'CropLand'}, \tag{31}$$

$$PYLandPast_l = PXLandAg_{l,'PastureLand'}, \tag{32}$$

$$PXLandCrop_{l,acrop} = RENTACRE_{l,acrop}, \tag{33}$$

$$PXLandPast_{l,apast} = RENTACRE_{l,apast}. \tag{34}$$

Once land heterogeneity and transformability have been reflected in the model, land in each alternative use is assumed homogeneous. As shown in figure 6, activities form a land composite ($ActLand$) from the different MLRAs where imperfect substitution is accounted for as well.

6 Institutions

In the CGE model, institutions are represented by nine household categories based on income levels, six federal and state government divisions, enterprises, investment, inventory and two trade accounts. Following, the model's mathematical statements reflecting each institution's income and expenditure will be detailed and explained.

6.1 Households

There are 9 household categories (h) based on annual income as mentioned before. Households and enterprises are endowed with primary factors of production (qf) and land (ql). By default, these endowments are assumed to be fixed to the observed base-year quantities. As formulated in equation (35), households' incomes ($HHINC$) are partially generated by the sale ($hhsales$) of commodities (c) at producer's prices (PQ). The volume of the sales is fixed at the base year quantity. Households receive a share ($shfinst$) of the net income received ($NETFINC$) by primary factors (f), valued at their respective wage (PF), from renting them to the production activities. They receive a share ($shlinst$) of the income from the land, in different MLRAs (l), rented to agricultural activities at their respective rental rates (PL). Households also receive a share ($shgovhh$) of the government's (gov) transferable income ($GOVTRNS$), a share ($shenthh$) of enterprises' transferable income ($ENTTNRS$), a share ($shinvhh$) of the investment account's transferable income ($INVTRNS$) and transfers ($trnsouthh$) from outside regions (t). The transfers coming from the investment account are considered borrowed capital for consumption.

$$\begin{aligned} HHINC_h = & \left(\sum_c hhsales_{h,c} * PQ_c\right) + \left(\sum_f NETFINC_f * PF_f * shfinst_{h,f}\right) \\ & + \left(\sum_l ql_l * PL_l * shlinst_{h,l}\right) + \left(\sum_h HHTRNS_h * shhhhh_{h,h}\right) \\ & + \left(\sum_{gov} GOVTRNS_{gov} * shgovhh_{h,gov}\right) + (ENTTNRS * shenthh_h) \\ & + (INVTRNS * shinvhh_h) + \left(\sum_t trnsouthh_{h,t}\right). \end{aligned} \tag{35}$$

As shown in equation (36), factor income transfered to households and enterprises ($NETFINC$) is net of factor taxes (tf) and depreciation ($deprec$) in the case of capital:

$$NETFINC_f = qf_f * \left(1 - \sum_{gov} tf_{gov,f} - deprec_f\right). \tag{36}$$

Households' incomes are subject to a tax (th) imposed by the government. As formulated in equation (37), after accounting for income taxes, a portion of the income ($HHTRNS$) is transfered to other institutions and, also, devoted to consumption and savings:

$$HHTRNS_h = HHINC_h * \left(1 - \sum_{gov} th_{gov,h}\right). \tag{37}$$

After accounting for transfers to other households ($shhhhh$) and to outside regions ($shhhout$), the net income ($HHNETINC$) devoted to commodity consumption and savings is formulated as in equation (38):

$$HHNETINC_h = HHTRNS_h * \left(1 - \sum_h shhhhh_{h,h} - \sum_t shhhout_{t,h}\right). \quad (38)$$

Utility production by each household, as depicted in figure 8, is modeled using a top nest ($HhTop$) where utility is maximized through the consumption of a composite consumer good ($QYHhCons$), at price ($PYHhCons$), and savings ($QHHSAV$), valued at their respective prices ($PHHSAV = 1$), up to the point when the budget constraint ($HHNETINC$) is met. A zero elasticity of substitution is specified by default for this nest (σ_{HhTop}) to reflect a constant marginal propensity to save.

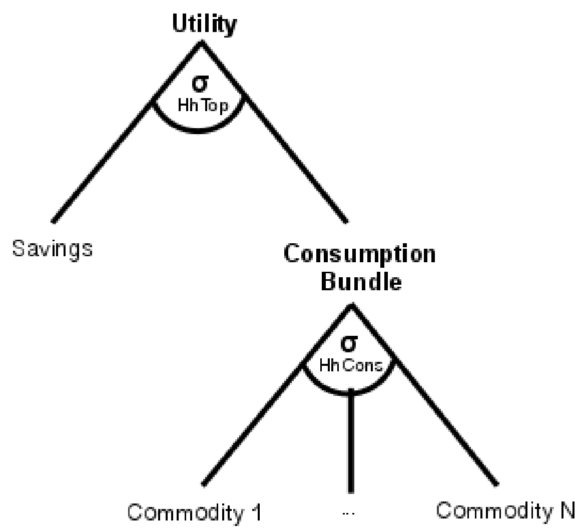

Figure 8: Representation of households utility production in the CGE model

The composite consumer good is the product of a subnest ($HhCons$) that reflects substitutability among commodities through an elasticity of substitution (σ_{HhCons}) of 0.5. Households are charged an aggregate sales tax for the consumption of the composite consumer good ($thhcons$):

$$\begin{aligned} HHNETINC_h \geq & [(QYHhCons_h * PYHhCons_h) * (1 + thhcons_h)] \\ & + [(PHHSAV_h) * (QHHSAV_h)] . \end{aligned} \quad (39)$$

6.2 Government

As mentioned before, there are 6 government divisions (gov). The different government divisions generate revenues ($GOVINC$) partially by selling commodities ($govsales$) at producer's prices (PQ), as formulated in equation (40).[7] The volume of sales is fixed at the base year quantity. Some divisions collect taxes and their respective tax rates are inferred from the base-year SAM. Taxes are levied on factor incomes (tf), households' incomes (th) and enterprises' income ($tent$). To accommodate to the IMPLAN SAM structure, a portion of the indirect business taxes (IBT) aggregate account has been modeled as a production tax (ta) from different activities (a) in the CGE model.[8] Hence, the tax is levied on the production by activity ($QYActTop$), valued at their respective

[7] Not all of the divisions sell commodities.

[8] ta does not include import duties since these were disaggregated and assigned to a new account in the SAM as explained in Monge (2012)

representative prices ($PYActTop$). Sales taxes are also collected for commodity purchases from the government ($tgovcons$), households ($thhcons$), inventory ($tnvtcons$) and investment ($tinvcons$) accounts. All taxes are distributed to the different government divisions according to a set of shares ($shtaxgov$) obtained from the base-year SAM. Duties collected from importing commodities from the rest of the world ($timp$) are directed to the federal government's non-defense division.

Some divisions also receive a share ($shgovgov$) from other divisions' transferable incomes ($GOVTRNS$), a share ($shinvgov$) from the investment account's transferable income ($INVTRNS$), and transfers from outside regions ($trnsoutgov$). The transfers coming from the investment account are considered borrowed capital.

$$
\begin{aligned}
GOVINC_{gov} = &\left(\sum_{c} govsales_{gov,c} * PQ_c\right) + \left(\sum_{f} qf_f * PF_f * tf_{gov,f}\right) \\
&+ shtaxgov_{gov} * \left(\sum_{a} QYActTop_a * PYActTop_a * ta_a\right) \\
&+ shtaxgov_{gov} * \left(\sum_{c,gov} QGOV_{c,gov} * PD_c * tgovcons_{gov}\right) \\
&+ shtaxgov_{gov} * \left(\sum_{h} QYHhCons_h * PYHhCons_h * thhcons_h\right) \\
&+ shtaxgov_{gov} * \left(\sum_{c} QNVT_c * PD_c * tnvtcons\right) \\
&+ shtaxgov_{gov} * \left(\sum_{c} QINV_c * PD_c * tinvcons\right) \\
&+ 1_{'fed\,non-def'} * \left(\sum_{t,c} QXComImp_{t,c} * PFOBIMP_{t,c} * timp_{t,c}\right) \\
&+ \left(\sum_{h} HHINC_h * th_{gov,h}\right) \\
&+ (ENTINC * tent_{gov}) + \left(\sum_{gov} GOVTRNS_{gov} * shgovgov_{gov,gov}\right) \\
&+ (INVTRNS * shinvgov) + \sum_{t} trnsoutgov_{gov,t}.
\end{aligned}
\tag{40}
$$

As shown in equation (41), government savings ($govsav$) is assumed to be fixed to the observed figures in the base-year SAM. After considering savings, a portion ($GOVTRNS$) of the revenue received by the government divisions is transfered to other institutions:

$$GOVTRNS_{gov} = GOVINC_{gov} - govsav_{gov}. \tag{41}$$

The government divisions' disbursements ($GOVEXP$) consist of fixed savings ($govsav$), government consumption of commodities ($QGOV$) valued at purchaser's prices (PD) and subject to an aggregate sales tax ($tgovcons$), and the transfer income ($GOVTRNS$) to households ($shgovhh$), to other government divisions ($shgovgov$), to enterprises ($shgovent$) and to outside regions ($shgovout$)

as formulated in equation (42):

$$
\begin{aligned}
GOVEXP_{gov} =& govsav_{gov} \\
&+ \left[\left(\sum_{c} QGOV_{c,gov} * PD_{c} \right) * (1 + tgovcons_{gov}) \right] \\
&+ GOVTRNS_{gov} * \left(\sum_{h} shgovhh_{h,gov} + \sum_{gov} shgovgov_{gov,gov} \right) \\
&+ GOVTRNS_{gov} * \left(shgovent_{gov} + \sum_{t} shgovout \right).
\end{aligned} \tag{42}
$$

To achieve a complete exhaustion of each government division's budget, government commodity consumption ($QGOV$) is flexible and adjusted from its base-year purchases ($qgov$) equiproportionately ($GOVADJ$) across consumed commodities as shown in equation (43):

$$QGOV_{c,gov} = qgov_{c,gov} * GOVADJ_{gov}. \tag{43}$$

6.3 Enterprises

There is only one representative account for enterprises ($'ent'$). Enterprises neither sell nor purchase commodities. As mentioned before, enterprises are also endowed with primary factors of production (qf) and land (ql). Again, these endowments are assumed to be fixed to the observed base-year quantities. Instead of distributing net factor incomes ($NETFINC$) directly to households, enterprises also receive a share ($shfinst$), valued at their respective wages (PF) as formulated in equation (44). Hence, a good portion of the income ($ENTINC$) generated by enterprises comes from primary factors. Enterprises also receive a share ($shlinst$) of the income from the land rented to agricultural activities at their respective rental rates (PL). Some of the government divisions' transferable income ($GOVTRNS$) is also devoted to enterprises ($shgovent$).

$$
\begin{aligned}
ENTINC =& \left(\sum_{f} NETFINC_{f} * PF_{f} * shfinst_{'ent',f} \right) \\
&+ \left(\sum_{l} ql_{l} * PL_{l} * shlinst_{'ent',l} \right) \\
&+ \left(\sum_{gov} GOVTRNS_{gov} * shgovent_{gov} \right).
\end{aligned} \tag{44}
$$

As shown in equation (45), after accounting for enterprises' income taxes ($tent$), the rest of the income received by enterprises is transfered ($ENTTRNS$) to other institutions:

$$ENTTRNS = ENTINC * \left(1 - \sum_{gov} tent_{gov} \right). \tag{45}$$

As formulated in equation (46), enterprises' disbursements ($ENTEXP$) consist of a tax payment ($tent$) levied on total income ($ENTINC$), and transfers ($ENTTRNS$) to households ($shenthh$) and the investment account ($shentinv$). It is important to note that the transfers to households are indirect factor income payments to households. The transfers to the investment account are considered savings and are adjusted proportionately to the income received.

$$\begin{aligned} ENTEXP = &\left(\sum_{gov} tent_{gov} * ENTINC\right) \\ &+ \left\{ENTTRNS * \left(\sum_{h} shenthh_h + shentinv\right)\right\}. \end{aligned} \tag{46}$$

6.4 Inventory

There is a representative account for inventories that generates income ($NVTINC$), partially, from the use of commodities in inventory ($nvtsales$) at producer's prices (PQ). It receives transfers from outside institutions ($trnsoutnvt$) and from net adittions to inventory ($nvtin$), meaning there are more additions to inventory than sales from it. As shown in equation (47), the only variable in the inventory income formulation is price, the rest being parameters fixed to the observed base-year figures:

$$NVTINC = \left(\sum_{c} nvtsales_c * PQ_c\right) + \sum_{t} trnsoutnvt_t + nvtin. \tag{47}$$

After accounting for fixed net inventory sales ($nvtout$), meaning there are more sales from inventory than additions to it, the inventory account's transferable income ($NVTTRNS$) to other institutions is formulated as in equation (48):

$$NVTTRNS = NVTINC - nvtout. \tag{48}$$

As shown in equation (49), inventory's total disbursements ($NVTEXP$) consist of commodities' purchases ($QNVT$) at purchaser's prices (PD) and charged an aggregate sales tax ($tnvtcons$), inventory's share ($shnvtout$) of transferable income ($NVTTRNS$) to outside regions, and net inventory sales:

$$\begin{aligned} NVTEXP = &\left[\left(\sum_{c} QNVT_c * PD_c\right) * (1 + tnvtcons)\right] \\ &+ \left(\sum_{t} shnvtout_t * NVTTRNS\right) \\ &+ nvtout. \end{aligned} \tag{49}$$

To completely exhaust its income, inventory's commodity consumption ($QNVT$) is flexible and adjusted from its base-year purchases ($qnvt$) equi-proportionately ($NVTADJ$) across consumed commodities as shown in equation (50):

$$QNVT_c = qnvt_c * NVTADJ. \tag{50}$$

6.5 Investment

There is a representative account for investment and it partially generates income ($INVINC$) from the sale of investment commodities ($invsales$) valued at producer's prices (PQ), as formulated in equation (51). It also receives a share ($deprec$) of the income generated by the capital primary factor (qf), valued at its respective price (PF), in the concept of depreciation or capital consumption allowance. Its receipts also consist of the savings generated by households ($QHHSAV$), valued at their respective prices ($PHHSAV$), fixed government savings ($govsav$), a share ($shentinv$) of enterprises' transferable income ($ENTTRNS$), fixed net inventory sales ($nvtout$) and variable net foreign investment (NFI). Net foreign investment is defined as the difference between foreign spending and receipts.

$$\begin{aligned} INVINC = &\left(\sum_c invsales_c * PQ_c\right) + (deprec_{'capital'} * qf_{'capital'} * PF_{'capital'}) \\ &+ \left(\sum_h QHHSAV_h * PHHSAV_h\right) + \sum_{gov} govsav_{gov} \\ &+ (ENTTRNS * shentinv) + nvtout + \sum_t NFI_t. \end{aligned} \tag{51}$$

After accounting for fixed net inventory additions ($nvtin$), the investment account's transferable income ($INVTRNS$) to other institutions is formulated as in equation (52):

$$INVTRNS = INVINC - nvtin. \tag{52}$$

Formulated in equation (53), investment's total disbursements consist of commodity purchases ($QINV$) valued at purchaser's prices (PD) and charged an aggregate sales tax ($tinvcons$), net inventory additions ($nvtin$), investment's income transfers ($INVTRNS$) to households ($shinvhh$), government divisions ($shinvgov$) and to outside regions ($shinvout$). The transfers to other institutions are considered borrowed capital by the different receiving institutions.

$$\begin{aligned} INVEXP = &\left[\left(\sum_c QINV_c * PD_c\right) * (1 + tinvcons)\right] \\ &+ INVTRNS * \left(\sum_h shinvhh_h + \sum_{gov} shinvgov_{gov} + \sum_t shinvout_t\right) \\ &+ nvtin. \end{aligned} \tag{53}$$

To completely exhaust its income, investment's commodity consumption ($QINV$) is flexible and adjusted from its base-year purchases ($qinv$) equi-proportionately ($INVADJ$) across consumed commodities as shown in equation (54):

$$QINV_c = qinv_c * INVADJ. \tag{54}$$

7 Commodity markets

7.1 Domestic

As figure 9 shows, all produced and imported commodities enter into the market. Any commodity produced by different domestic sources (activities or institutions) is assumed to be perfectly substitutable and bundled into an aggregate domestic output valued at producer's prices (PQ).[9] Aggregate domestic output is allocated under the assumption that suppliers seek to maximize revenues for any given aggregate output level subject to imperfect transformability, between exports and domestic demand, expressed through a CET function ($ComDist$). An elasticity of transformation ($\sigma_{ComDist}$) of -2.5 is used by default for this nest to reflect a high degree of transformation.

The share of a commodity that is not exported is supplied to the domestic market, at domestic prices ($PDom$), and bundled with imports (if imported) into a composite commodity through a

[9] As opposed to Lofgren et al. (2002) where activity outputs are considered imperfectly substitutable and a CES function is used to aggregate domestic output by activities.

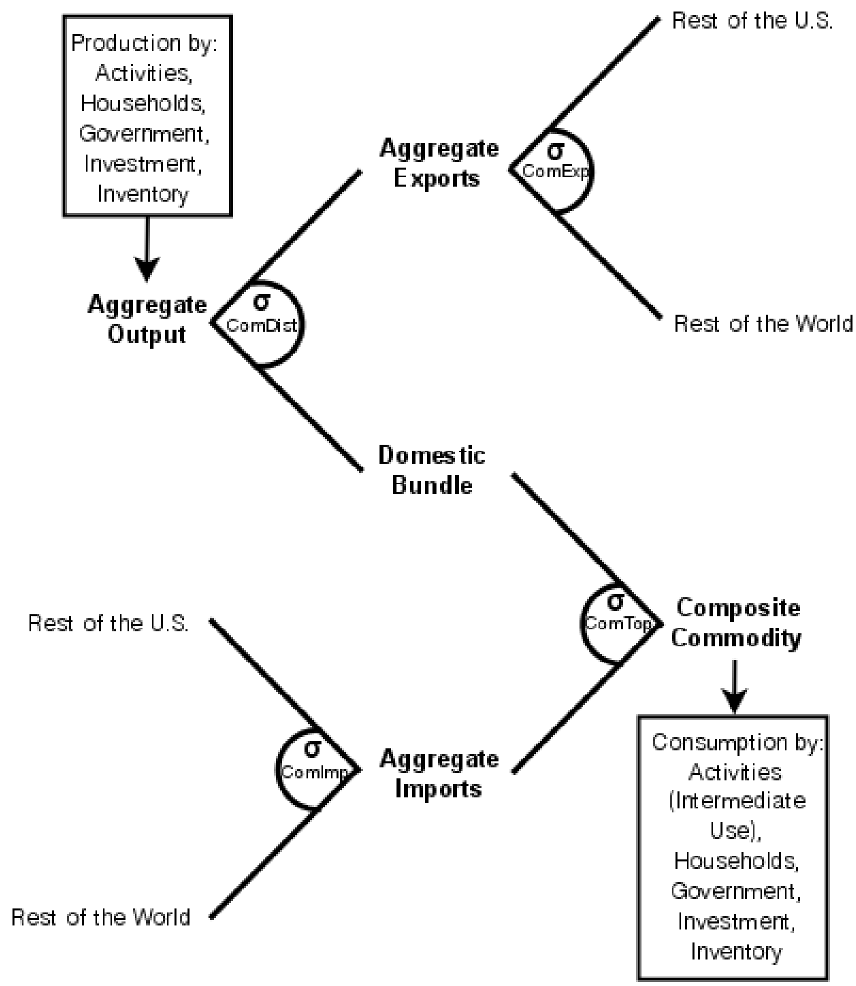

Figure 9: Representation of commodity markets in the CGE model

CES function ($ComTop$). This composite commodity is aggregated under the assumption that demanders seek to minimize costs subject to imperfect substitutability between imports and domestic supply, according to the Armington convention (Armington, 1969). An elasticity of substitution (σ_{ComTop}) of 2.5 is used by default for this nest to reflect a high degree of substitution. The composite commodity is demanded by end users (activities and institutions) at purcharser's prices (PD).

On the demand side, the model has been designed to find the same market-clearing purchaser's price (PD) across all final consumers for each commodity, equilibrating final demand and composite-commodity supply as shown in equation (55). In the CGE model, activity and institutional consumption is flexible.

$$\begin{aligned} QYComTop_c \geq & \sum_h QXHHCons_{h,c} + \sum_a QXActInt_{a,c} \\ & + \sum_{gov} QGOV_{gov,c} + QNVT_c + QINV_c \qquad \perp PYComTop_c. \end{aligned} \tag{55}$$

On the supply side, the model will find the same market-clearing producer's price (PQ) across all domestic producers for each comodity, equilibrating domestic supply and aggregate-output demand as shown in equation (56). In the basic CGE model, only production by activities is flexible, institutional production is fixed to the base-year SAM.

$$\begin{aligned} QYComDist_c \leq & \sum_a QXJntPrd_{a,c} + \sum_h hhsales_{h,c} \\ & + \sum govsales_{gov,c} + nvtsales_c + invsales_c \quad \perp PYComDist_c. \end{aligned} \tag{56}$$

In the modified IMPLAN SAM, indirect business taxes include sales, production and factor-use taxes. Due to the aggregated nature (and treatment as a production tax in this model) of the indirect business taxes account and to the non-existence of margin accounts (transportation and retail), all commodity transactions in an IMPLAN SAM are expressed in producer's prices. In the model, activities bear the entire burden of the taxes related to commodity production, except import duties. Hence, producer's prices already include these taxes.[10]

7.2 Trade

Since the model is designed to accommodate large and small regional aggregations within the U.S., an exchange rate is not necessary due to the negligible effect that small aggregations would exert on world prices. Hence, traded commodities and institutional transfers are valued at the local currency (U.S. dollars). The model assumes the existence of a representative exporter and importer for commodity-trading purposes. The exporter seeks to maximize revenues by selling aggregate export commodities, to the rest of the U.S. and the rest of the world, and subject to imperfect transformability formulated through a CET function ($ComExp$) as depicted in figure 9. An elasticity of transformation (σ_{ComExp}) of -2.5 is used by default for this nest to reflect a high degree of transformation.

On the other side, the importer seeks to minimize costs by purchasing commodities, from the rest of the U.S. and the rest of the world, and subject to imperfect substitutability expressed as a CES function ($ComImp$) as depicted in figure 9. Commodities imported from the rest of the world were subject to import duties. An elasticity of substitution (σ_{ComImp}) of 2.5 is used by default for this nest to reflect a high degree of substitution.

As shown in equation (57), export demands to outside regions are a function of base-year SAM export quantities ($qexp$) and prices ($pexp$), prices charged by the representative exporter ($PXComExp$) and export demand elasticities (ϵ):

$$QEXP_{c,t} = qexp_{c,t} * (1 + \epsilon_{c,t}) * \left(\frac{PXComExp_{c,t} - pexp_{c,t}}{pexp_{c,t}} \right), \tag{57}$$

where $PXComExp$ is estimated as a shadow price of the excess supply equation for exports to each destination:

$$QXComExp_{c,t} \geq QEXP_{c,t} \perp PXComExp_{c,t}, \tag{58}$$

where $QXComExp$ is the quantity supplied by the $ComExp$ nest.

Import supplies from outside regions are a function of base-year SAM import quantities ($qimp$) and prices ($pimp$), free-on-board (FOB) prices charged by the representative foreign exporter at the foreign port ($PFOBIMP$) and import supply elasticities (κ) as formulated in equation (59):

$$QIMP_{t,c} = qimp_{t,c} * (1 + \kappa_{t,c}) * \left(\frac{PFOBIMP_{t,c} - pimp_{t,c}}{pimp_{t,c}} \right), \tag{59}$$

[10] For any parametrical shock in the CGE model, the vector of market-clearing prices at a solution shows differences between producer's prices (PQ) and purcharser's prices (PD). This difference is due to the effect of import and export prices, respectively.

where the price paid by the representative importer (PIMP) is the FOB price after accounting for import duties:

$$PIMP_{t,c} = PFOBIMP_{t,c} * (1 + timp_{t,c,}) , \tag{60}$$

where PFOBIMP is estimated as a shadow price of the excess supply equation for imports from each source:

$$QIMP_{t,c} \geq QXComImp_{t,c} \perp PFOBIMP_{t,c}, \tag{61}$$

where $QXComImp$ is the quantity demanded by the ComImp nest.

8 Macroeconomic balances

8.1 Government balance

To completely exhaust the different government divisions' budgets, the closure rule followed in the CGE structure is flexible government commodity consumption ($QGOV$) and fixed savings ($govsav$). The adjustment factor ($GOVADJ$) in equation (43) helps to achieve this balance and is paired to equation (62), following the syntax required by PATH to solve mixed complementarity problems.

$$GOVINC_{gov} = GOVEXP_{gov}. \tag{62}$$

8.2 Inventory balance

To achieve a balance for the inventory account, the closure rule followed in the basic CGE structure is flexible inventory commodity consumption ($QNVT$) and fixed net inventory deletions ($nvtout$). Again, the adjustment factor ($NVTADJ$) in equation (50) helps to achieve this balance and is paired to equation (63).

$$NVTINC = NVTEXP. \tag{63}$$

8.3 Investment balance

The same closure rule followed for the two previous institutions is applied to the investment account - investment commodity consumption ($QINV$) is flexible. However, net foreign income (NFI) is also flexible in this case, as will be explained later. The adjustment factor ($INVADJ$) in equation (54) helps to achieve this balance and is paired to equation (64).

$$INVINC = INVEXP. \tag{64}$$

8.4 External balance

As previously mentioned, the model is designed to accommodate large and small regional aggregations within the U.S. Hence, an exchange rate variable is not necessary due to the negligible effect that small aggregations would exert on world prices. Thus, the closure variable for the trade accounts is net foreign investment (NFI). As shown in equation (65), the left-hand-side variables reflect receipts by the trade accounts consisting of commodity import quantities ($QIMP$) valued at their respective import FOB prices ($PFOBIMP$), and the different transfers to outside regions by factors ($shfout * NETFINC$), households ($shhhout * HHTRNS$), government divisions ($shgovout * GOVTRNS$), investment ($shinvout * INVTRNS$) and inventory ($shnvtout * NVTTRNS$). The right-hand-side variables and parameters represent transfers from outside regions such as commodity export quantities ($QEXP$) valued at their respective export prices ($PEXP$), foreign transfers to households ($trnsouthh$), government divisions ($trnsoutgov$), inventory ($trnsoutnvt$) and investment account or net foreign investment (NFI).

As previously listed in table 2, variables are represented by upper-case latin letters without a bar and parameters with lower-case Latin letters without a bar. Hence, $QIMP$, $PFOBIMP$, $NETFINC$, $HHTRNS$, $GOVTRNS$, $INVTRNS$, $NVTTRNS$, $QEXP$, $PEXP$ and NFI are all flexible endogenous variables that adjust according to the model's closure rules such as equation (65). The parameters $shfout$, $shhhout$, $shgovout$, $shinvout$, $shnvtout$, $trnsouthh$, $trnsoutgov$, $trnsoutnvt$ are taken and fixed to the 2008 base year SAM.

It is important to mention that all transfers are variables that adjust according to the total income from the different institutions. Prices and quantities of imported and exported commodities are variables. The expenditures from the different institutions that are treated as transfers to outside regions are estimated using shares from the base year SAM multiplied by the transferable institutional income variable. Transfers coming from outside regions to domestic institutions are treated as fixed parameters and do not change from the baseline. Net foreign investment (NFI) is the variable that is adjusted at last and the one that completes the model's closure.

$$\begin{aligned}
&\left(\sum_c QIMP_{c,t} * PFOBIMP_{c,t}\right) \\
&+ \left(\sum_f shfout_{t,f} * NETFINC_f\right) \\
&+ \left(\sum_h shhhout_{t,h} * HHTRNS_h\right) \\
&+ \left(\sum_{gov} shgovout_{t,gov} * GOVTRNS_{gov}\right) \\
&+ (shinvout_t * INVTRNS) \\
&+ (shnvtout_t * NVTTRNS) \\
&= \\
&\left(\sum_c QEXP_{c,t} * PEXP_{c,t}\right) \\
&+ \sum_h trnsouthh_{h,t} \\
&+ \sum_{gov} trnsoutgov_{gov,t} \\
&+ trnsoutnvt_t \\
&+ NFI_t.
\end{aligned} \tag{65}$$

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Appendix

Table 3: Total of County-level Recorded Acreage of Crops in 2008

IMPLAN code	IMPLAN industry	% of acres recorded	Crops included	
1	Oilseeds	98%	Canola	Mustard
			Flaxseed	Safflower
			Soybean	Rapeseed
			Sunflower	Sesame
2	Grains	98%	Corn Grain	Sorghum Silage
			Corn Silage	Wheat
			Barley	Pea Dry Edible
			Beans Dry Edible	Cowpea
			Oats	Lentils
			Rice	Buckwheat
			Rye	Popcorn
			Sorghum Grain	Wild Rice
7	Tobacco	89%	Tobacco	
8	Cotton	99%	Cotton Upland	Cotton Pima
9	Sugarcane and beets	99%	Sugarbeets	Sugarcane Seed
			Sugarcane Sugar	
10	All others	78%	Hay	Bluegrass
			Peanuts	Bromegrass
			Alfalfa	Fescue
			Birdsfoot	Ochardgrass
			Crimson Clover	Ryegrass
			Red Clover	Sudangrass
			White Clover	Timothy
			Lespedeza	Wheatgrass
			Vetch	Guar
			Bahia Grass	Hops
			Bentgrass	Mint Oil
			Bermuda Grass	

	Activities	Commodities	Factors	Indirect business taxes	Households	Government	Enterprises	Investment[a]	Inventory	Rest of the US	Rest of the world
Activities		5								38	
Commodities	1				16	21		30	35		
Factors	2										
Indirect business taxes	3										
Households		6	10		17	22	27	31		39	
Government		7	11	15	18	23	28	32		40	
Enterprises			12			24					
Investment ***		8	13		19	25	29		36	41	
Inventory		9						33		42	
Rest of the US	4		14		20	26		34	37	43	
Rest of the world											

[a] Investment account: (1) Payments by capital to institutions is considered net borrowing and (2) payments by institutions to capital is considered net saving

Figure 10: Detailed structure of an IMPLAN SAM

Table 4: Concepts of the Detailed Structure of an IMPLAN SAM in Figure 10

SAM ID	Concept	SAM ID	Concept
1	Domestic intermediate commodity inputs	23	Intergovernment transfers
2	Payments to factors	24	Transfers to enterprises
3	Producer, factor use and sales taxes	25	Government savings
4	Imports of goods and services by activities	26	Commodity imports and transfers by government
5	Domestic commodity output	27	Surplus to households, dividends
6	Households production of commodities and services	28	Corporate profit tax, surplus to government
7	Government production of commodities and services	29	Enterprise savings, retained earnings
8	Used and second hand goods [a]	30	Domestic capital goods consumption
9	Use of inventory to produce commodities	31	Dis-savings or withdrawals of capital for consumption
10	Factor income to households	32	Dis-savings or net borrowing by the government
11	Factor income to government, factor taxes	33	Net inventory change. Dis-savings of inventory [b]
12	Factor income to enterprises, corporate profits	34	Commodity imports and transfers by investment
13	Depreciation or capital consumption allowance	35	Stored commodities or in inventory
14	Factor imports and transfers	36	Net inventory change [c]
15	Sales excise and property taxes, etc.	37	Commodity imports and transfers by inventory
16	Domestic households consumption	38	Exports of goods and services by activities
17	Interhousehold transfers, interests	39	Commodity exports and transfers by households
18	Income and personal tax	40	Commodity exports and transfers by government
19	Savings (surplus or deficit)	41	Net foreign investment [d]
20	Commodity imports and transfers by households	42	Commodity exports and transfers by inventory
21	Domestic government consumption	43	Trans-shipments: imports to exports
22	Transfers to households		

[a] Old equipment or tear down of structures and selling off parts

[b] Capital payments to inventory represent dis-savings of inventory. In other words, there are more additions to inventory than sales from it.

[c] Inventory payments to capital is a net balance of inventory. In other words, there are more sales from inventory than additions to it.

[d] Net foreign investment = Exports - Imports

<table>
<tr><th></th><th>Activities</th><th>Commodities</th><th>Agricultural land</th><th>Factors</th><th>Indirect business taxes</th><th>Households</th><th>Enterprises</th><th>Government</th><th>Investment[a]</th><th>Inventory</th><th>Import taxes</th><th>Rest of the US</th><th>Rest of the world</th></tr>
<tr><td>Activities</td><td></td><td>5</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Commodities</td><td>1</td><td></td><td></td><td></td><td></td><td>20</td><td></td><td>29</td><td>36</td><td>42</td><td></td><td colspan="2">47</td></tr>
<tr><td>Agricultural land</td><td>2</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Factors</td><td>3</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td colspan="2">48</td></tr>
<tr><td>Indirect business taxes</td><td>4</td><td></td><td></td><td></td><td></td><td>21</td><td></td><td>30</td><td>37</td><td>43</td><td></td><td></td><td></td></tr>
<tr><td>Households</td><td></td><td>6</td><td>12</td><td>14</td><td></td><td>22</td><td>26</td><td>31</td><td>38</td><td></td><td></td><td colspan="2">49</td></tr>
<tr><td>Enterprises</td><td></td><td></td><td>13</td><td>15</td><td></td><td></td><td></td><td>32</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Government</td><td></td><td>7</td><td></td><td>16</td><td>19</td><td>23</td><td>27</td><td>33</td><td>39</td><td></td><td>46</td><td colspan="2">50</td></tr>
<tr><td>Investment ***</td><td></td><td>8</td><td></td><td>17</td><td></td><td>24</td><td>28</td><td>34</td><td></td><td>44</td><td></td><td colspan="2">51</td></tr>
<tr><td>Import taxes</td><td></td><td>9</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Inventory</td><td></td><td>10</td><td></td><td></td><td></td><td></td><td></td><td></td><td>40</td><td></td><td></td><td colspan="2">52</td></tr>
<tr><td>Rest of the US</td><td></td><td rowspan="2">11</td><td></td><td rowspan="2">18</td><td></td><td rowspan="2">25</td><td></td><td rowspan="2">35</td><td rowspan="2">41</td><td rowspan="2">45</td><td></td><td></td><td></td></tr>
<tr><td>Rest of the world</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
</table>

[a] Investment account: (1) Payments by capital to institutions is considered net borrowing and (2) payments by institutions to capital is considered net saving

Figure 11: Final modified Social Accounting Matrix (SAM)

Table 5: Concepts of the Final Modified Social Accounting Matrix (SAM) in Figure 11

SAM ID	Concept	SAM ID	Concept
1	Aggregate domestic and imported intermediate inputs	27	Corporate profit tax, surplus to government
2	Agricultural land rent payments	28	Enterprise savings, retained earnings
3	Payments to factors	29	Aggregate domestic and imported government consumption
4	Sales, Production, factor use taxes	30	Sales taxes to government
5	Aggregate domestic and exported commidity output	31	Transfers to households
6	Aggregate domestic and exported households production	32	Intergovernment transfers
7	Aggregate domestic and exported government production	33	Transfers to enterprises
8	Aggregate domestic and expoted production second hand goods [a]	34	Government savings
9	Import duties by commodity	35	Transfers from government to outside regions
10	Inventories used for domestic production or exports	36	Aggregate domestic and imported purchase of capital goods
11	Imports of commodities and services	37	Sales taxes to the investment account
12	Households income from agricultural land rents	38	Dis-savings or withdrawals of capital for consumption
13	Enterprises Income from agricutlural land rents	39	Dis-savings or net borrowing by the government
14	Factor income to households	40	Net inventory change. Dis-savings for inventory [b]
15	Factor income to enterprises, corporate profits	41	Transfers from investment to outside regions
16	Factor income to government, factor taxes	42	Aggregate domestic and imported commodities in inventory
17	Depreciation or capital consumption allowance	43	Sales taxes from inventory
18	Factor imports and transfers	44	Net inventory change [c]
19	Sales, Production, factor use taxes	45	Transfers from inventory to outside regions
20	Aggregate domestic and imported households consumption	46	Import duties
21	Sales taxes to households	47	Exports of goods and services
22	Interhousehold transfers, interests	48	Transfers from outside regions to factors
23	Income and personal tax	49	Transfers from outside regions to households
24	Savings (surplus or deficit)	50	Transfers from outside regions to government
25	Transfers from households to outside regions	51	Net foreign investment [d]
26	Surplus to households, dividends	52	Transfers from outside regions to inventory

[a] Old equipment or tear down of structures and selling off parts

[b] Capital payments to inventory represent dis-savings of inventory. In other words, there are more additions to inventory than sales from it.

[c] Inventory payments to capital is a net balance of inventory. In other words, there are more sales from inventory than additions to it.

[d] Net foreign investment = Exports - Imports

Table 6: Base Year Social Accounting Matrix (SAM) Parameters

Param	SAM	Param	SAM
tf	$\frac{SAM_{gov,f}}{SAM_{'total',f}}$	$shhhhh$	$\frac{SAM_{h,h}}{SAM_{'total',h}-SAM_{gov,h}}$
th	$\frac{SAM_{gov,h}}{SAM_{'total',h}}$	$shgovhh$	$\frac{SAM_{h,gov}}{SAM_{'total',gov}-SAM_{'inv',gov}}$
ta	$\frac{SAM_{'ibt',a}}{SAM_{'total',a}}$	$shenthh$	$\frac{SAM_{h,'ent'}}{SAM_{'total','ent'}-SAM_{gov,'ent'}}$
$tent$	$\frac{SAM_{gov,'ent'}}{SAM_{'total','ent'}}$	$shinvhh$	$\frac{SAM_{h,'inv'}}{SAM_{'total','inv'}-SAM_{'nvt','inv'}}$
$timp$	$\frac{SAM_{'imptax',c}}{SAM_{'row',c}}$	$shgovgov$	$\frac{SAM_{gov,gov}}{SAM_{'total',gov}-SAM_{'inv',gov}}$
$tgovcons$	$\frac{SAM_{'ibt',gov}}{SAM_{c,gov}}$	$shinvgov$	$\frac{SAM_{gov,'inv'}}{SAM_{'total','inv'}-SAM_{'nvt','inv'}}$
$thhcons$	$\frac{SAM_{'ibt',h}}{SAM_{c,h}}$	$shgovent$	$\frac{SAM_{'ent',gov}}{SAM_{'total',gov}-SAM_{'inv',gov}}$
$tnvtcons$	$\frac{SAM_{'ibt','nvt'}}{SAM_{c,'nvt'}}$	$shentinv$	$\frac{SAM_{'inv','ent'}}{SAM_{'total','ent'}-SAM_{gov,'ent'}}$
$tinvcons$	$\frac{SAM_{'ibt','inv'}}{SAM_{c,'inv'}}$	$shfout$	$\frac{SAM_{t,f}}{SAM_{'total',f}-SAM_{gov,f}-SAM_{'inv',f}}$
$deprec$	$\frac{SAM_{'inv','capital'}}{SAM_{'total','capital'}}$	$shhhout$	$\frac{SAM_{t,h}}{SAM_{'total',h}-SAM_{gov,h}}$
qf	$SAM_{'total',f}$	$shgovout$	$\frac{SAM_{t,gov}}{SAM_{'total',gov}-SAM_{'inv',gov}}$
ql	$SAM_{'total',l}$	$shnvtout$	$\frac{SAM_{t,'nvt'}}{SAM'_{total','nvt'}-SAM_{'inv','nvt'}}$
$shfinst$	$\frac{SAM_{hhent,f}}{SAM_{'total',f}-SAM_{gov,f}-SAM_{'inv',f}}$	$shinvout$	$\frac{SAM_{t,'inv'}}{SAM_{'total','inv'}-SAM_{'nvt','inv'}}$
$shlinst$	$\frac{SAM_{hhent,l}}{SAM_{'total',l}}$	$shtaxgov$	$\frac{SAM_{gov,'ibt'}}{SAM_{'total','ibt'}}$
$hhsales$	$SAM_{h,c}$	$trnsouthh$	$SAM_{hh,t}$
$govsales$	$SAM_{gov,c}$	$trnsoutgov$	$SAM_{gov,t}$
$nvtsales$	$SAM_{'nvt',c}$	$trnsoutnvt$	$SAM_{'nvt',t}$
$invsales$	$SAM_{'inv',c}$	$nvtin$	$SAM_{'nvt','inv'}$
$qgov$	$SAM_{c,gov}$	$nvtout$	$SAM_{'inv','nvt'}$
$qnvt$	$SAM_{c,'nvt'}$	$govsav$	$SAM_{'inv',gov}$
$qinv$	$SAM_{c,'inv'}$	$qexp$	$SAM_{c,t}$
$qimp$	$SAM_{t,c}$		

	Activities	Commodities	Agricultural Land	Factors	Indirect Business Taxes	Households	Enterprises	Government	Investment	Inventory	Import duties	Trade	TOTAL
Activities		6											60
Commodities	1					23		34	42	49		55	
Agricultural Land	2												61
Factors	3												62
Indirect Business Taxes	4					24		35	43	50			
Households		7	13	16		25	30	36	44			56	63
Enterprises			14	17				37					64
Government		8		18	22	26	31	38	45		54	57	65
Investment		9		19		27	32	39		51		58	66
Inventory		10							46			59	67
Import duties		11											
Trade		12		20		28		40	47	52			
TOTAL	5		15	21		29	33	41	48	53			

Figure 12: Mathematical interpretation of the Computable General Equilibrium (CGE) Model and Social Accounting Matrix (SAM)

Table 7: Formulas for Mathematical Interpretation of the Computable General Equilibrium (CGE) and Social Accounting Matrix (SAM) Included in Figure 12

SAM ID	Formula	SAM ID	Formula
1	$QXActInt_{c,a} * PXActInt_{c,a}$	18	$tf_{gov,f} * qf_f * PF_f$
2	$QXActLand_{l,a} * PXActLand_{l,a}$	19	$deprec_f * qf_f * PF_f$
3	$QXActVad_{f,a} * PXActVad_{f,a}$	20	$shfout_{t,f} * qf_f * PF_f$
4	$QYActTop_a * PYActTop_a * ta_a$	21	$qf_f * PF_f$
5	$QYActTop_a * PYActTop_a$	22	$QYActTop_a * PYActTop_a * ta_a * shtaxgov_{gov}$
6	$QXJntPrd_{a,c} * PXJntPrd_{a,c}$	23	$QXHhCons_{c,h} * PXHhCons_{c,h}$
7	$hhsales_{h,c} * PQ_c$	24	$QYHhCons_h * PYHhCons_h * thhcons_h$
8	$govsales_{gov,c} * PQ_c$	25	$shhhhh_{h,h} * HHTRNS_h$
9	$invsales_c * PQ_c$	26	$th_{gov,h} * HHINC_h$
10	$nvtsales_c * PQ_c$	27	$QHHSAV_h * PHHSAV_h$
11	$QXComImp_{t,c} * PFOBIMP_{t,c} * timp_{t,c}$	28	$shhhout_{t,h} * HHTRANS_h$
12	$QXComImp_{t,c} * PFOBIMP_{t,c}$	29	$HHEXP_h$
13	$shlinst_{h,l} * q_l * PL_l$	30	$shenthh_h * ENTTRNS$
14	$shlinst_{'ent',l} * q_l * PL_l$	31	$tent_{gov} * ENTINC$
15	$ql_l * PL_l$	32	$shentinv * ENTTRNS$
16	$shfinst_{h,f} * qf_f * PF_f$	33	$ENTEXP$
17	$shfinst_{'ent',f} * qf_f * PF_f$	34	$QGOV_{c,gov} * PD_c$

Table 7: Continued

SAM ID	Formula	SAM ID	Formula
35	$\sum_c QGOV_{c,gov} * PD_c * tgovcons_{gov}$	52	$shnvtout_t * NVTTRNS$
36	$shgovhh_{h,gov} * GOVTRNS_{gov}$	53	$NVTEXP$
37	$shgovgov_{gov,gov} * GOVTRNS_{gov}$	54	$\sum_{t,c} QXComImp_{t,c} * PFOBIMP_{t,c} * timp_{t,c}$
38	$shgovent_{gov} * GOVTRNS_{gov}$	55	$QEXP_{c,t} * PEXP_{c,t}$
39	$govsav_{gov}$	56	$trnsouthh_{h,t}$
40	$shgovout_{t,gov} * GOVTRNS_{gov}$	57	$trnsoutgov_{gov,t}$
41	$GOVEXP_{gov}$	58	NFI_t
42	$QINV_c * PD_c$	59	$trnsoutnvt_t$
43	$\sum_c QGOV_{c,gov} * PD_c * tgovcons_{gov}$	60	$QYActTop_a * PQActTop_a$
44	$shinvhh_h * INVTRNS$	61	$\sum_a ActLand_{l,a}$
45	$shinvgov_h * INVTRNS$	62	$\sum_a ActVad_{f,a}$
46	$nvtin$	63	$HHINC_h$
47	$shinvout_{t,gov} * INVTRNS_{gov}$	64	$ENTINC$
48	$INVEXP$	65	$GOVINC_{gov}$
49	$QNVT_c * PD_c$	66	$INVINC$
50	$\sum_c QNVT_c * PD_c * tnvtcons$	67	$NVTINC$
51	$nvtout$		

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