A New Approach to Labor Mobility In CGE Models with Application to an Archetype SSA Country*

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1. INTRODUCTION

Labor mobility often has a strong impact on the effects of changes in policies on social and economic outcomes. Therefore, it is important both in the real world and in economic models. The CGE literature includes a variety of approaches to mobility and other aspects of labor market functioning. In this paper, we present and test an innovative approach that has several attractive features. The approach draws on Dantzig's classic transportation model and the product-space literature that is due to Hausmann and coauthors. It is applied to a CGE model and database for a Sub-Saharan African (SSA) economy.

The essence of our approach is that labor is viewed as having capabilities specific to the sector in which it is working. As a result, labor that moves from one sector to another is less effective than the labor that already works in the receiving sector. The extent of this efficiency shortfall depends on the extent to which the capabilities that are required from workers in the two sectors are different; using product-space terminology, it depends on the distance between the two sectors (or the opposite, their proximity). In slightly more technical modeling terms, in the base-year dataset, each labor force category (one or more, perhaps disaggregated on the basis of educational attainment) is assigned sectoral capabilities; in practice, this allocation may simply reflect the base year employment structure. The proximity of a sector A to a sector B determines the ease with which labor in sector A can be reallocated to sector B. A distinction is made between physical and effective labor quantities. For labor that stays within its sector of origin (or moves to a sector considered to be in the same location, if such sectors exist), physical and effective labor quantities are identical. If labor moves to a different location, the effective labor quantity received in the sector of destination falls short of the effective (and physical) quantity of labor that departs from the sector of origin; the longer the distance (the lower the proximity), the larger this shortfall. Profit-maximizing producers consider the gap between effective and physical labor in their hiring decisions, preferring labor that already works in the sector. Over time, the sectoral allocation of labor may evolve on the basis of past labor reallocations, reflecting learning by doing. A key attractive feature of this treatment is that it, realistically, views labor segmentation along a continuum as opposed to the common dichotomy of treating labor in different sectors as belonging either to the same segment or to different, separate segments. However, the two extremes of this common dichotomy can still be captured as the special cases of sectors that are treated as being in the same location or at distances that are so great that migration from one to the other is precluded due to the loss in effective labor that is involved. In other respects, our approach is consistent with alternative, common treatment of non-mobility aspects of labor market functioning, including the determination of total employment for each labor type, the units used for labor quantities, and the treatment of substitutability between labor categories within sectors. With regard to data, the product-space literature provides a default approach for the definition of sectoral proximity data but other options may be considered. In simulations, this treatment provides a means of avoiding excessive short-run adjustments in labor force allocation in response to economic shocks.

We proceed as follows: Section 2 presents our approach in the context of a brief discussion of alternative approaches to labor mobility in CGE models. The approach is tested in Section 3 [in progress] in a set of comparative-static simulations of the effects of export price shocks for processed food products with alternative parameterizations of the labor market. Conclusions are presented in Section 4 [in progress]. Appendix A explains the proximity concept of the product-space literature. A full mathematical statement of our model is provided in Appendix B while Appendix C [in progress] presents the results from systematic sensitivity analysis with respect to selected elasticities.

2. METHOD AND DATA

2.1. Alternative Treatments of labor mobility in CGE Models

The CGE literature includes a large variety of treatments of the labor market, including labor mobility, which is the focus of this paper. As a reference point, it may be helpful to remind the reader of the relatively standard and simple CGE treatment of labor that is found in Lofgren et al. (2002) where, for each labor type (for example categorized on the basis of education or "skill"), (a) the demand side is represented by first-order conditions for producer profit-maximization in the form of a value-added function and an equation that, for each production sector, imposes equality between the wage and the marginal revenue product of labor; (b) the quantity of labor supplied for employment is exogenous; and (c) a labor market equilibrium condition imposes equality between quantities demanded and supplied, an outcome that is realized via adjustments in an economy-wide wage variable. Labor is measured in physical units (i.e., number of full-time workers employed during one year). Base-year wages, which vary across activities, are computed on the basis of data on labor incomes (from the SAM) and employment quantities. For any labor type, this market-clearing mechanism does not change base-year relative wages by sector; it merely imposes a uniform scaling of the wages across all activities. Each labor type is fully mobile across the activities in which it is employed; a worker that moves from one sector to another earns the same wage and is as productive as those who already work in the receiving sector.

The CGE literature includes numerous alternative approaches that in different ways deviate from this simple formulation, including the treatment of labor supply (which alternatively may be endogenous, driven by utility-maximizing household decisions or by a wage curve), labor units and sectoral wage differences (with wages normalized to unity across all sectors and, accordingly, one unit of the labor the quantity that earns a wage of one). An additional dimension of variation is in the treatment of value-added, where different functional forms and nestings of labor and other factors have been used.

With regard to labor mobility, the focus of this paper, instead of perfect mobility, different types of segmentation are common with each segment including one or more activities. Segments may either be watertight compartments or allow for imperfect mobility (migration) between segments. According to one type of segmentation, labor activities are classified as rural or urban. Migration between the two may draw on the Harris-Todaro model with urban unemployment and migration ensuring equality between the rural wage and the expected urban wage, with explicit unemployment in the urban area; explicit unemployment requires that the wage in urban areas is not free to clear the urban labor market (Dervis et al., 1982, pp. 178-180).[1] In the absence of urban unemployment, the rural-urban migration model is in the same spirit as the formulation in Lofgren et al. (2002), described above in the sense that, in both cases, in response to shocks, labor is reallocated to maintain exogenous relative wage differences. Under a related approach, proposed by Flaig (2014, pp. 119-121), labor migrates to pools linked to multiple segments (with perfect mobility within each pool) or between pairs of segments, with each segment representing labor employed in one or more sectors. In both cases, migration depends on relative wage changes in different segments and response elasticities. In the GTAP model, the allocation of labor and other factors with imperfect mobility (which are "sluggish") is determined by a constant-elasticity-of-transformation (CET) function, with the allocations responding to changes in relative wages across activities [Hertel and Tsigas, 1997, pp. 51-52). Like formulations with labor units derived from normalization of wages to unity, the units of labor employed in different sectors do not correspond to physical units.

2.2. A Proximity-based Approach to Labor Segmentation

Our proximity-based formulation, which is embedded in a standard CGE model (see Appendix B) is derived from producer profit maximization in a setting where product space proximity

[1] One problem with rural-urban segmentation is that sectors of production in economic data cannot readily be split into rural and urban; to various degrees, production in all sectors takes place both in rural and urban areas, and workers residing in rural (urban) areas may work in urban (rural) areas.

influences the profitability of the reallocation of factors between sectors, in the following referred to as activities. A simplified version of the profit-maximization problem of the producer in activity *a* may be stated as follows:[2]

$$\text{maximize } p_a \cdot Q_a - \sum_f \sum_{a'} w_{f,a'} \cdot QFR_{f,a',a}$$

subject to

$$Q_a = \alpha_a \left[\sum_f \delta_{f,a} \cdot fp_{f,a}{}^{-\rho} \cdot QF_{f,a}{}^{-\rho} \right]^{-1/\rho}$$

$$\left[\text{quantity of output for } a\right] = \left[\text{CES function of effective factor employment in } a\right]$$

$$QF_{f,a} = \sum_{a'} \varphi_{f,a',a} \cdot QFR_{f,a',a}$$

$$\begin{bmatrix}\text{effective quantity of} \\ f \text{ employed in } a\end{bmatrix} = \begin{bmatrix}\text{sum of physical quantities reallocated from act-} \\ \text{ivities } a', \text{ scaled by proximities betwen } a' \text{ and } a\end{bmatrix}$$

$$QFR_{f,a',a} \geq 0$$

$$\left[\text{physical quantity of } f \text{ reallocated from } a' \text{ to } a\right] \geq 0$$

where p_a = output price; Q_a = output quantity; $w_{f,a'}$ = market wage per physical unit of factor *f* linked in source activity *a'*; $QFR_{f,a',a}$ = the physical quantity of *f* reallocated from source activity *a'* to the current activity *a*; α_a, $\delta_{f,a}$, ρ, and $fp_{f,a}$ = CES function parameters for efficiency, factor shares, exponent, and factor-specific productivity, respectively; $QF_{f,a}$ = effective employed quantity of factor *f* in activity *a*; $\varphi_{f,a',a}$ = proximity between any source activity *a'* and the

[2] To simplify, this mathematical statement suppresses domain controls, the time index, and the activity subscript for the exponent ρ. For simplicity, this discussion also abstracts from intermediate inputs, exogenous relative wage differences between activities, and unemployment based on a wage curve; these features are all present in the model application in Section 3.

current destination activity *a* with respect to factor *f* ($0 < \varphi_{f,a',a} \leq 1$, with a value of 1 for the special case where *a = a',* which also is covered by *QFR* variable (i.e., the case of reallocation of a factor to its original activity, with identical physical and effective factor quantities. A proximity of 1 is also used for activities that, from a capabilities perspective, are considered identical. A very low proximity value would preclude reallocation of *a'* to *a*. Between these extremes, parameter settings may reflect a continuum of intermediate cases with different degrees of segmentation as labor that moves from *a* to *a'* suffers from different degrees of efficiency loss compared to labor that originally worked in *a'*. For factors without this factor reallocation mechanism, the proximity parameter is 1 for all relevant a-a' mappings, putting them in the same, economy-wide pool.[3]

Finally, as noted, the proposed treatment is inspired by Dantzig's transportation model (Dantzig 1963, pp. 35-42). In his model, the cost of transporting a set of items from supply to demand depots is minimized subject to demand and supply constraints, with a transportation cost of zero when the demand and supply depots are in the same location. In our approach, the items are physical units of labor and the unit transportation costs are replaced by effective employment losses driven by proximity measures. In both settings, the order in which a demand location draws on different supplies depends on the market wage or price in the supply location and the loss that is imposed when relocating a good or a unit of labor from one location to the other.

Returning to the optimization problem, its Lagrangian, *L*, may be stated as follows:

$$L = p_a \cdot Q_a - \sum_f \sum_{a'} w_{f,a'} \cdot QFR_{f,a'a} + V_a \left[\alpha_a \left[\sum_f \delta_{f,a} \cdot fp_{f,a}{}^{-\rho} \cdot QF_{f,a}{}^{-\rho} \right]^{-1/\rho} - Q_a \right]$$

[3] Note that upper-/lower-case Latin letters are used for the variables that are endogenous/ exogenous to the producer. In the CGE model, two of these exogenous variables, p_a and $w_{f,a}$, are endogenous.

$$+\sum_f R_{f,a}\left[\sum_{a'}\varphi_{f,a',a}\cdot QFR_{f,a',a}-QF_{f,a}\right]$$

where V_a = the shadow price of output; $R_{f,a}$ = the efficiency-unit shadow rent of factor *f* in activity *a*. The first-order conditions may be rendered as:

1. $\frac{\partial L}{\partial Q_a}=p_a-V_a=0$

2. $\frac{\partial L}{\partial QF_{f,a}}=(-1/\rho)V_a\cdot\alpha_a\left[\sum_{f'}\delta_{f',a}\cdot fp_{f',a}{}^{-\rho}\cdot QF_{f',a}{}^{-\rho}\right]^{-1/\rho-1}\left[(-\rho)\cdot\delta_{f,a}\cdot fp_{f,a}{}^{-\rho}\cdot QF_{f,a}{}^{-\rho-1}\right]-R_{f,a}=0$

3. $\frac{\partial L}{\partial QFR_{f,a',a}}=-w_{f,a'}+R_{f,a}\cdot\varphi_{f,a',a}\le 0;$

4. $QFR_{f,a',a}\ge 0;$

5. $QFR_{f,a'a}\left(-w_{f,a'}+R_{f,a}\cdot\varphi_{f,a',a}\right)=0$

6. $\frac{\partial L}{\partial V_a}=\alpha_a\left[\sum_f\delta_{f,a}\cdot fp_{f,a}{}^{-\rho}\cdot QF_{f,a}{}^{-\rho}\right]^{-1/\rho}-Q_a=0$

7. $\frac{\partial L}{\partial r_{f,a}}=\sum_{a'}\varphi_{f,a',a}\cdot QFR_{f,a',a}-QF_{f,a}=0$

Using 1 to substitute for *V* in 2, noting that $(-1/\rho)\cdot(-\rho)=1$, and rearranging the remaining equations permits us to summarize the first-order conditions for producer profit maximization as follows (with the above equation numbers in parenthesis):

8 (1-2). $p_a\cdot\alpha_a\left[\sum_{f'}\delta_{f',a}\cdot fp_{f',a}{}^{-\rho}\cdot QF_{f',a}{}^{-\rho}\right]^{-1/\rho-1}\left[\delta_{f,a}\cdot fp_{f,a}{}^{-\rho}\cdot QF_{f,a}{}^{-\rho-1}\right]=R_{f,a}$

$[\text{marginal value product of factor } f \text{ in activity } a]=[\text{shadow wage of factor } f \text{ in activity } a]$

9 (3). $w_{f,a'}\ge R_{f,a}\cdot\varphi_{f,a',a}$

$$\begin{bmatrix}\text{market wage}\\ \text{of } f \text{ in } a'\end{bmatrix}\ge\begin{bmatrix}\text{shadow wage of wage of } f \text{ in } a \text{ scaled}\\ \text{by the proximity between } a' \text{ and } a\end{bmatrix}$$

10 (4). $QFR_{f,a',a} \geq 0$

$\left[\text{quantity reallocated from } a' \text{ to } a \right] \geq 0$

11 (5). $QFR_{f,a',a}\left(R_{f,a} \cdot \varphi_{f,a',a} - w_{f,a'}\right) = 0$

$$\begin{bmatrix} \text{the quantity of } f \text{ reallocated from } a' \text{ to } a \text{ TIMES the gap between (i) the shadow wage} \\ \text{of } f \text{ in } a \text{ scaled by the proximity between } a' \text{ and } a \text{ (ii) the market wage of } f \text{ in } a' \end{bmatrix} = 0$$

12 (6). $Q_a = \alpha_a \left[\sum_f \delta_{f,a} \cdot fp_{f,a}{}^{-\rho} \cdot QF_{f,a}{}^{-\rho} \right]^{-1/\rho}$

$\left[\text{quantity of output for } a \right] = \left[\text{CES function of effective factor employment in } a \right]$

13 (7). $QF_{f,a} = \sum_{a'} \varphi_{f,a',a} \cdot QFR_{f,a',a}$

$$\begin{bmatrix} \text{Effective quantity} \\ \text{of } f \text{ employed in } a \end{bmatrix} = \begin{bmatrix} \text{sum of physical quantities from activities} \\ a' \text{ scaled by proximities betwen } a' \text{ and } a \end{bmatrix}$$

The preceding set of equations all appear in the CGE model, which is implemented as a mixed-complementarity problem.[4] As indicated by the objective function, activities pay the wage of origin, $w_{f,a'}$, to each physical unit of any labor type *f*. According to equation 11, if a positive quantity of *f* is reallocated from *a'* to *a*, the market wage of *f* in source activity *a'* must equal to the shadow rent per efficiency unit of *f* in destination activity *a, R,* scaled by the proximity indicator.[5] This means that, the lower the proximity parameter, the higher the effective-unit destination sector shadow wage, *R*, that is required for reallocation to take place and that a

[4] The model is implemented in the GAMS software using the PATH solver.

[5] This naturally follows from profit maximization; if, in equation 9 the LHS is smaller/larger than the RHS, then an increase/decrease in the reallocated quantity would raise profits. In terms of the simulations in Section 3, an increase in the export price for outputs from activity a raises the unit output price for activity *a* and the shadow wage of *f* in *a* (equation 8) and inducing activity *a* to increase factor employment (as otherwise the LHS in equation 9 is smaller than the RHS).

proximity set close to zero for any pair of activities *a′* and *a* in effect would rule out reallocation between this pair of activities, putting them in fully separated segments of the labor market. To maximize profits, activities tend to prioritize hiring labor already employed in its segment (including labor that already is in the activity), since the effective units of labor do not fall short of the physical units for which the activity pays wages. After this, if it is optimal to expand employment beyond the pool of labor in the own segment, prioritizing activities with high proximities.[6]

As opposed to the producer maximization problem, the CGE model also requires a factor market equilibrium condition, which may be stated as follows:

$$\sum_{a} QFR_{f,a',a} = \overline{QFR}_{f,a'}$$

where $\overline{QFR}_{f,a'}$ is the physical quantity of factor *f* that is available for reallocation from activity of origin *a′*. In words, this condition imposes equality between (a) the sum of the physical quantities of labor *f* from *a′* that are reallocated to any activity *a* and (b) the available supply of factor *f* for activity *a′*. This equilibrium condition is cleared by the related wage variable, $w_{f,a'}$, which in the CGE model is endogenous.

Compared to a standard CGE model, additional data is needed for the proximity parameter. As indicated, the values for this parameter determine the structure and degree of labor market segmentation. Drawing on the PS literature, proximities may be computed on the basis of revealed comparative advantage (RCA) data computed on the basis of international trade statistics; in the product-space literature, this indicator is used to define the extent to which

[6] Similarly, preference for hiring workers already in place in a firm is also generated by labor market insider-outsider theories, albeit due to largely different reasons -- labor turnover costs among which lower productivity (due to absent skills) is only one part (cf. Lindbeck, Assar, and Dennis J. Snower. 1988. The Insider-Outside Theory of Employment and Unemployment. MIT Press.)

sectors are similar in capabilities. However, databases for relevant trade statistics, most importantly COMTRADE, exclude a subset of the goods sectors and all service sectors. In an economy-wide context and given that goods and service activities operate in the same labor markets, it is necessary to extend the proximity measures to cover excluded sectors which, in most countries, are less traded (and tradable) than COMTRADE sectors, as manifested in relatively low export/output and import/demand ratios. If the outputs of a sector are relatively non-traded, export data do not provide a good measure of RCA (the standard capability indicator in PS analysis) or proximity (in capabilities); for sectors without exports, it is obviously not possible to measure proximity or capability in this way. Given their availability and the fact that they conceptually seem more appropriate, we turn to disaggregated value-added data to generate RCA and proximity indicators for non-COMTRADE sectors, thereby ensuring exhaustive sector coverage. Thus, we view non-COMTRADE sectors as constituting an integral part of the sectoral structure, both in their own right and by making different paths of structural transformations more or less difficult for COMTRADE sectors.[7] Further, before the CGE implementation of the "raw" proximities that area generated in this manner, scaling is needed to generate empirically valid representations of labor market segmentation.[8] This is

[7] In fact, this treatment addresses a shortcoming of PS analysis: it may often be misleading to analyze strategies for structural transformation without considering the role of services or other sectors not covered by COMTRADE.

[8] In our application in Section 3, the scaled proximity parameter used in the model is derived from the original proximity parameter using the following formula: $\varphi_{a',a} = \varphi_{a',a}^{raw} + \varphi^{scal} \cdot \left(1 - \varphi_{a',a}^{raw}\right)$, where φ^{scal} = factor-specific scaling parameter. To ensure that $0 \leq \varphi_{a,a't} \leq 1$, it should satisfy the following restriction: $-\varphi_{a',a,t}^{raw} \Big/ \left(1 - \varphi_{a',a,t}^{raw}\right) \leq \varphi^{scal} \leq 1$. Note that $\lim_{\varphi^{scal} \to 1} \left(\varphi_{a',a}^{raw} + \varphi^{scal} \cdot \left(1 - \varphi_{a',a}^{raw}\right)\right) = 1$. If the non-scaled proximities are too low, simulated factor reallocation falls short of what is observed in practice; to make reallocation easier, the value of the scaling parameter should be within the following range: $0 < \varphi^{scal} \leq 1$.

part of the broader challenge of testing and improving the validity of CGE models in manners that consider the context of different types of applications.

In a dynamic setting, the size of the pools by labor factor and activity may be adjusted over time in response to learning by doing. For example, for each activity, the labor pool(s) may be a weighted average of the share of the labor force that it employed in recent years. If so, if the labor share of an activity increases in year *t* but does not change in later years, then the effective employment losses due to reallocation would gradually decline starting from year *t+1*, mimicking learning by doing.[9]

2.2. DATA

The bulk of the dataset is for the simulation base-year – a social accounting matrix (SAM); stocks and sectoral employment levels for production factors (including different types of labor and capital), population, as well as a set of elasticities (for production, consumption, and trade), and a baseline projection for growth in GDP at factor cost.

Like other CGE models, our CGE uses a base-year SAM (in this case for 2010), to define base-year values for the bulk of the model parameters, including production technologies, sources of commodity supplies (domestic output or imports), demand patterns (for household and government consumption, investment and exports), transfers between different institutions, interest rates, and tax rates. The disaggregation of the archetype SSA country SAM coincides with that of the rest of the model database. As shown in Table 2.1, it is disaggregated into 25 sectors (activities and commodities) – 3 in agriculture, 2 in mining, 13 in manufacturing, and 7

[9] If only the shares of the last year are used, then the effective employment loss would only be imposed in a single year. By using a weighted average of a series of recent years, it is possible to gradually reduce effective employment losses over time, mimicking a process of more gradual learning by doing.

in services – with each activity producing a single commodity for which it is the only domestic producer. The factors are split into labor, private capital, and natural resources (5 types: agricultural land, forestry land, fishing resources, and two natural resources used in extractive industries). The institutions are split into households, government, and the rest of world. A set of auxiliary accounts cover the different tax instruments as well as trade and transport margins on domestic sales, imports and exports.

Table 2.1: disaggregation of archetype SSA country CGE and SAM

Category - #	Category	Item	Category - #	Item
Sectors (activities and commodities) (25)	**Agriculture (3)**	Agriculture	**Factors (7)**	Labor
		Forestry		Private capital
		Fishing		Land
	Mining (2)	Petroleum and gas		Timber
		Mining		Fish
	Manufacturing (13)	Food		Extractive res in Pet and gas
		Beverages		Extractive res in Mining
		Tobacco product	**Institutions (3)**	Households
		Textiles and leather		Government
		Wood		Rest of the world
		Paper	**Auxiliary accounts (7)**	Taxes on production
		Refined petroleum products		Taxes on sales
		Chemical products		Taxes on imports
		Rubber and plastic		Taxes on income
		Non-metalic mineral products		Trade and transp marg, dom
		Metal products		Trade and transp marg, imp
		Machinery and vehicles		Trade and transp marg, exp
		Other manufactures	**Savings and Investment (4)**	Savings
	Services (7)	Electricity and gas		Private (non-government)
		Construction		Government
		Trade, hotels and resturants		Stock change
		Transport		
		Communications		
		Government		
		Other services		

Source: Authors' elaboration.

On the basis of SAM data, Table 2.3 summarizes the sectoral structure of the archetype SSA economy in 2010: sectoral shares in value-added, production, employment, exports and imports, as well as the split of domestic sectoral supplies between exports and domestic sales, and domestic sectoral demands between imports and domestic output. For instance, while (primary) agriculture represents a significant share of employment (around 66 percent), its shares of value added (VA), production, and exports are much smaller (in the range of 15-25 percent).[10] The share of its output that is exported is around 10 percent while only some 5 percent of domestic demands are met via imports.

[10] The sectoral structure according to the national accounts (regularly published by UBOS) and the 2009/10 Supply and Use Tables are not fully consistent: for example, according to former, the share of agriculture in GDP was 17.5% in 2009/10 while, according to the latter, it was 24.4%.

Table 2.3: Sectoral structure of archetype SSA country's economy in 2010 (percent)

Sector	VAshr	PRDshr	EMPshr	EXPshr	EXP-OUTshr	IMPshr	IMP-DEMshr
Agriculture	24.6	15.9	59.7	21.3	10.2	4.6	4.8
Forestry	4.6	3.1	5.4	0.0	0.1	0.0	0.1
Fishing	1.3	0.8	0.9	3.9	33.0	0.0	0.4
Petroleum and gas	0.1	0.1	0.0	0.0	0.1	0.0	0.1
Mining	1.1	1.1	0.2	0.6	3.5	1.4	16.8
Food	7.2	11.3	2.9	12.6	9.0	7.0	10.5
Beverages	0.9	1.7	0.1	2.9	13.3	1.1	14.3
Tobbaco product	0.1	0.2	0.0	0.3	15.1	0.2	39.3
Textiles and leather	1.0	1.0	0.2	8.4	56.4	4.9	64.4
Wood	0.0	0.5	0.0	0.4	6.5	0.2	5.7
Paper	0.1	0.1	0.0	0.5	30.9	1.9	63.7
Refined petroleum products	0.0	0.1	0.0	1.0	97.7	16.2	84.7
Chemical products	1.1	1.3	0.1	3.1	17.2	11.1	59.2
Rubber and plastic	0.2	0.2	0.0	1.0	33.3	2.1	68.8
Non-metalic mineral products	0.8	1.2	0.1	3.1	20.3	2.6	29.4
Metal products	0.8	1.3	0.1	5.4	34.7	8.2	59.0
Machinery and vehicles	0.1	0.2	0.0	2.7	98.5	27.4	99.9
Other manufactures	0.6	1.0	0.1	0.9	7.3	1.9	23.4
Electricity and gas	0.5	0.4	0.1	0.5	10.4	0.1	3.8
Construction	6.6	11.3	2.0	0.0	0.0	0.0	0.0
Trade, hotels and resturants	14.9	17.2	8.2	15.8	8.3	2.1	1.9
Transport	2.5	2.3	1.3	2.8	10.9	3.9	21.4
Communications	3.7	3.6	0.8	0.0	0.0	0.0	0.0
Other gov services	3.5	3.8	3.5	8.1	19.3	0.5	2.2
Other services	23.8	20.3	14.1	4.6	2.1	2.4	1.7
Total	100.0	100.0	100.0	100.0	8.1	100.0	15.8

where VAshr = value-added share (%); PRDshr = production share (%); EMPshr = share in total employment (%); EXPshr = sector share in total exports (%); EXP-OUTshr = exports as share in sector output (%); IMPshr = sector share in total imports (%); IMP-DEMshr = imports as share of domestic demand (%).

Source: Authors' calculations based on 2010 archetype SSA country SAM and employment data.

Table 2.4 shows the factor shares in total sectoral value added. For example, the table shows that agriculture is relatively intensive in the use of labor; this information will be useful to analyze the results from the CGE simulations.

Table 2.4: Sectoral factor intensity in 2010 (percent)

Sector	Labor	Prv Capital	Nat Res	Total
Agriculture	73.7	15.0	11.3	100.0
Forestry	36.0	0.3	63.7	100.0
Fishing	21.1	0.2	78.7	100.0
Petroleum and gas	27.3	38.1	34.6	100.0
Mining	27.3	51.5	21.2	100.0
Food	68.9	31.1	0.0	100.0
Beverages	23.0	77.0	0.0	100.0
Tobacco product	66.1	33.9	0.0	100.0
Textiles and leather	39.6	60.4	0.0	100.0
Wood	14.6	85.4	0.0	100.0
Paper	27.3	72.7	0.0	100.0
Refined petroleum products	9.3	90.7	0.0	100.0
Chemical products	19.2	80.8	0.0	100.0
Rubber and plastic	17.6	82.4	0.0	100.0
Non-metalic mineral products	17.4	82.6	0.0	100.0
Metal products	17.9	82.1	0.0	100.0
Machinery and vehicles	15.1	84.9	0.0	100.0
Other manufactures	30.0	70.0	0.0	100.0
Electricity and gas	41.6	58.4	0.0	100.0
Construction	50.7	49.3	0.0	100.0
Trade, hotels and resturants	49.6	50.4	0.0	100.0
Transport	48.8	51.2	0.0	100.0
Communications	19.6	80.4	0.0	100.0
Other government services	100.0	0.0	0.0	100.0
Other services	52.9	47.1	0.0	100.0
Total	55.7	37.3	7.0	100.0

Source: Authors' calculations based on 2010 archetype SSA country SAM.

The computed raw proximity data between all pairs of commodities are shown in Table 2.4. As explained in the Appendix A, this is the key building-block for all network indicators in the PS analysis.

Table 2.5: Proximity between sectors in the archetype SSA country SAM

		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
1	Agriculture	1.00	0.48	0.49	0.23	0.46	0.80	0.46	0.36	0.44	0.39	0.23	0.25	0.20	0.26	0.31	0.43	0.10	0.16	0.48	0.46	0.64	0.57	0.46	0.26	0.23
2	Forestry	0.48	1.00	0.48	0.14	0.27	0.52	0.45	0.39	0.50	0.59	0.34	0.30	0.25	0.41	0.43	0.42	0.18	0.25	0.47	0.49	0.48	0.51	0.50	0.16	0.25
3	Fishing	0.49	0.48	1.00	0.22	0.39	0.51	0.54	0.49	0.46	0.37	0.29	0.22	0.24	0.27	0.34	0.31	0.17	0.27	0.34	0.43	0.46	0.32	0.40	0.32	0.32
4	Petroleum and gas	0.23	0.14	0.22	1.00	0.26	0.16	0.08	0.11	0.15	0.25	0.11	0.41	0.08	0.03	0.14	0.13	0.08	0.04	0.26	0.22	0.27	0.22	0.21	0.15	0.07
5	Mining	0.46	0.27	0.39	0.26	1.00	0.38	0.35	0.29	0.31	0.35	0.23	0.31	0.20	0.09	0.22	0.49	0.03	0.26	0.32	0.33	0.37	0.36	0.40	0.37	0.20
6	Food	0.80	0.52	0.51	0.16	0.38	1.00	0.52	0.43	0.49	0.44	0.26	0.30	0.25	0.33	0.39	0.36	0.10	0.26	0.49	0.51	0.56	0.57	0.46	0.28	0.25
7	Beverages	0.46	0.45	0.54	0.08	0.35	0.52	1.00	0.48	0.45	0.43	0.40	0.25	0.25	0.40	0.50	0.42	0.18	0.30	0.32	0.49	0.38	0.39	0.50	0.33	0.50
8	Tobacco product	0.36	0.39	0.49	0.11	0.29	0.43	0.48	1.00	0.51	0.48	0.26	0.21	0.26	0.42	0.45	0.31	0.18	0.45	0.28	0.39	0.37	0.32	0.44	0.24	0.34
9	Textiles and leather	0.44	0.50	0.46	0.15	0.31	0.49	0.45	0.51	1.00	0.38	0.21	0.28	0.21	0.38	0.49	0.38	0.08	0.36	0.36	0.39	0.40	0.44	0.38	0.13	0.18
10	Wood	0.39	0.59	0.37	0.25	0.35	0.44	0.43	0.48	0.38	1.00	0.43	0.28	0.10	0.40	0.45	0.44	0.25	0.30	0.47	0.45	0.37	0.46	0.44	0.23	0.25
11	Paper	0.23	0.34	0.29	0.11	0.23	0.26	0.40	0.26	0.21	0.43	1.00	0.18	0.22	0.48	0.43	0.36	0.41	0.26	0.26	0.33	0.23	0.27	0.33	0.37	0.55
12	Refined petroleum products	0.25	0.30	0.22	0.41	0.31	0.30	0.25	0.21	0.28	0.28	0.18	1.00	0.26	0.15	0.30	0.31	0.12	0.21	0.36	0.39	0.19	0.37	0.38	0.24	0.18
13	Chemical products	0.20	0.25	0.24	0.08	0.20	0.25	0.25	0.26	0.21	0.10	0.22	0.26	1.00	0.33	0.30	0.16	0.26	0.30	0.11	0.27	0.15	0.19	0.25	0.38	0.45
14	Rubber and plastic	0.26	0.41	0.27	0.03	0.09	0.33	0.40	0.42	0.38	0.40	0.48	0.15	0.33	1.00	0.62	0.33	0.48	0.45	0.26	0.39	0.21	0.34	0.40	0.30	0.52
15	Non-metalic mineral products	0.31	0.43	0.34	0.14	0.22	0.39	0.50	0.45	0.49	0.45	0.43	0.30	0.30	0.62	1.00	0.51	0.30	0.35	0.40	0.49	0.27	0.42	0.44	0.24	0.38
16	Metal products	0.43	0.42	0.31	0.13	0.49	0.36	0.42	0.31	0.38	0.44	0.36	0.31	0.16	0.33	0.51	1.00	0.24	0.31	0.53	0.53	0.35	0.49	0.50	0.20	0.29
17	Machinery and vehicles	0.10	0.18	0.17	0.08	0.03	0.10	0.18	0.18	0.08	0.25	0.41	0.12	0.26	0.48	0.30	0.24	1.00	0.33	0.21	0.22	0.17	0.22	0.23	0.27	0.41
18	Other manufactures	0.16	0.25	0.27	0.04	0.26	0.26	0.30	0.45	0.36	0.30	0.26	0.21	0.30	0.45	0.35	0.31	0.33	1.00	0.26	0.31	0.17	0.29	0.27	0.22	0.31
19	Electricity and gas	0.48	0.47	0.34	0.26	0.32	0.49	0.32	0.28	0.36	0.47	0.26	0.36	0.11	0.26	0.40	0.53	0.21	0.26	1.00	0.47	0.45	0.56	0.42	0.19	0.15
20	Construction	0.46	0.49	0.43	0.22	0.33	0.51	0.49	0.39	0.39	0.45	0.33	0.39	0.27	0.39	0.49	0.53	0.22	0.31	0.47	1.00	0.29	0.49	0.51	0.29	0.39
21	Trade, hotels and resturants	0.64	0.48	0.46	0.27	0.37	0.56	0.38	0.37	0.40	0.37	0.23	0.19	0.15	0.21	0.27	0.35	0.17	0.17	0.45	0.29	1.00	0.49	0.38	0.19	0.19
22	Transport	0.57	0.51	0.32	0.22	0.36	0.57	0.39	0.32	0.44	0.46	0.27	0.37	0.19	0.34	0.42	0.49	0.22	0.29	0.56	0.49	0.49	1.00	0.47	0.20	0.19
23	Communications	0.46	0.50	0.40	0.21	0.40	0.46	0.50	0.44	0.38	0.44	0.33	0.38	0.25	0.40	0.44	0.50	0.23	0.27	0.42	0.51	0.38	0.47	1.00	0.35	0.40
24	Government	0.26	0.16	0.32	0.15	0.37	0.28	0.33	0.24	0.13	0.23	0.37	0.24	0.38	0.30	0.24	0.20	0.27	0.22	0.19	0.29	0.19	0.20	0.35	1.00	0.48
25	Other services	0.23	0.25	0.32	0.07	0.20	0.25	0.50	0.34	0.18	0.25	0.55	0.18	0.45	0.52	0.38	0.29	0.41	0.31	0.15	0.39	0.19	0.19	0.40	0.48	1.00

Source: Authors' calculations based on COMTRADE and GTAP 8 data.

In addition to the SAM, our CGE model also requires (a) base-year estimates for sectoral employment levels,[11] and (b) a set of elasticities (for production, consumption and trade). In order to estimate sectoral employment we combined population data with estimates for sectoral employment shares in broad sectoral categories from the WDI. In turn, elasticities were given a value based on the available evidence for comparable countries. For elasticities, the following values were used: (a) the elasticity of substitution among factors is in the 0.2–1.15 range, relatively low for primary sectors and relatively high for manufactures and services (see Narayanan et al. 2015); (b) the expenditure elasticities for household consumption were obtained from Seale et al. (2003); and (c) trade elasticities are 4 for both Armington and CET elasticities.[12] Given the uncertainty with respect to our elasticity values, in Appendix C we conduct a systematic sensitivity analysis of our simulation results with respect to their values.

3. SIMULATIONS

[11] The unemployment rate is implicitly fixed in the current set of simulations. Under an alternative setting, it is explicit and endogenous using a wage-curve formulation. If this formulation were used, we would also need base-year unemployment data and an unemployment elasticity for the wage curve; drawing on Blanchflower and Oswalrd (2005), an unemployment elasticity of -0.1 is commonly used in CGE applications.

[12] These CET and Armington elasticities may seem high. However, the size of responses to trade-related shocks depend not only on these trade elasticities but also on other aspects of the model, including the size of production responses which, in their turn, depend on (a) the mobility of labor and other factors; and (b) elasticities of factor substitution. Thus, a given trade-related shock may generate similar trade and production responses with a combination of high factor mobility and low trade elasticities or, alternatively, low factor mobility and high trade elasticities.

3.1. Scenarios

3.2. Results

4. Conclusions

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APPENDIX A: THE PROXIMITY CONCEPT IN PRODUCT-SPACE ANALYSIS

PS analysis, which was pioneered in Hausmann, Hwang, and Rodrik (2007), Hausmann and Klinger (2006), and Hidalgo et al. (2007), offers a data-driven evaluation of the feasibility and desirability of alternative sectoral transformation options for a country, considering its initial structure and the global record. In this paper, we only use one concept that is specific to PS analysis, proximity, which draws on the standard trade concept of revealed comparative advantage (RCA). In PS analysis, the proximity of one sector to another is the core indicator of how close the two sectors are in terms of the capabilities needed for competitive production. In this paper, we apply it to labor as an indicator of the closeness of the capabilities required in different sectors from labor that otherwise belong to the same category (where categories may represent skills, educational levels, or occupations).

RCA shows the degree of comparative advantage by country, commodity, and time. A country has an RCA in a commodity *c* if the following indicator has a value above unity:

$$RCA_{r,c,t} = \frac{\dfrac{E_{r,c,t}}{\sum_{c'} E_{r,c',t}}}{\dfrac{\sum_{r'} E_{r',c,t}}{\sum_{r'}\sum_{c'} E_{r',c',t}}} = \frac{\begin{bmatrix}\text{shr of commodity} \\ \text{in country exports}\end{bmatrix}}{\begin{bmatrix}\text{shr of commodity} \\ \text{in world exports}\end{bmatrix}} = \frac{\dfrac{E_{r,c,t}}{\sum_{r'} E_{r',c,t}}}{\dfrac{\sum_{i'} E_{r,c',t}}{\sum_{r'}\sum_{c'} E_{r',c',t}}} = \frac{\begin{bmatrix}\text{shr of country in} \\ \text{exports of commodity}\end{bmatrix}}{\begin{bmatrix}\text{shr of country in} \\ \text{world exports}\end{bmatrix}}$$

where *E* stands for export value (in US$) while the indices *r* (or *r′*), *c* (or *c′* or *c′′*), and *t* stand for countries ("regions"), commodities (often referred to as products, typically limited to goods), and years, respectively[13]. We name the related binary 0-1 variable *RCA01* ($RCA01_{r,c,t}$ = 0 if $RCA_{r,c,t} < 1$; $RCA01_{r,c,t} = 1$ if $RCA_{r,c,t} \geq 1$).

[13] In PS analysis, the indices *c* and *i* are typically used for country and product; in our CGE and many other CGE models, *c* is used for commodities (goods or services). In order to avoid confusion and to keep notation consistent throughout this study, we switch to *r* for countries (or "regions"; this follows the example of GTAP) and use *c* for commodities. It should also be noted that our CGE makes a distinction between commodities *c*

The proximity between two commodities, c and c', in time t, $\varphi_{c,c',t}$ $\left(0 \leq \varphi_{c,c',t} \leq 1\right)$ is derived from data on probabilities of having RCA ≥ 1 (*rca01* = 1) simultaneously for c and c':

$$\varphi_{c,c',t} = \min\left\{ P\left(rca01_{c,t} \middle| rca01_{c',t} \right), P\left(rca01_{c',t} \middle| rca01_{c,t} \right) \right\}$$

where *P* (the conditional probability) is computed using all countries *r* in year *t,* and where

$$rca01_{r,c,t} = \begin{Bmatrix} 1 \text{ if } RCA_{r,c,t} > 1 \\ 0 \text{ if } RCA_{r,c,t} \leq 1 \end{Bmatrix}$$

The PS-based proximity indicator in our application follows the disaggregation of the CGE database and covers both COMTRADE and non-COMTRADE commodities. For the former, the COMTRADE database is used; for the latter, we use 2007 data in the GTAP 8 database. The non-COMTRADE commodities consist of services and a small subset of goods (including utilities and construction). Globally and in most individual countries, the export shares in total output for these commodities are very small compared to the shares for COMTRADE commodities. Given this, we used GTAP VA data for the non-COMTRADE PS indicators. Technically, it is straightforward to define RCA and proximity indicators using export data for one commodity subset and VA data for another commodity subset. The economic interpretation is that, for relatively non-traded commodities (for which we rely on GTAP VA data), the degree of comparative (or competitive) advantage for a country is measured by how important a commodity is in the VA of a country compared to their importance in global VA. At the same time, for relatively tradable commodities (covered by COMTRADE export data), the degree of comparative advantage for country is measured in a standard manner by the how important a commodity is in the exports of a country compared to its importance in global exports. In effect, this combined formulation makes it possible to consider in an integrated manner the existing patterns in terms of the development of capabilities in service sectors in parallel with goods sectors.

(outputs) and activities *a* (producing outputs); in this application, there is a one-to-one mapping between the two.

APPENDIX B: MODEL MATHEMATICAL STATEMENT

In this section, the structure of the CGE model is presented. Figure C.1 and C.2 summarize the modeling of the production and consumption sides of the economy, respectively. In the lower part of each block, we present the corresponding variable name – see the model mathematical statement below.

Figure C.1: modeling of production

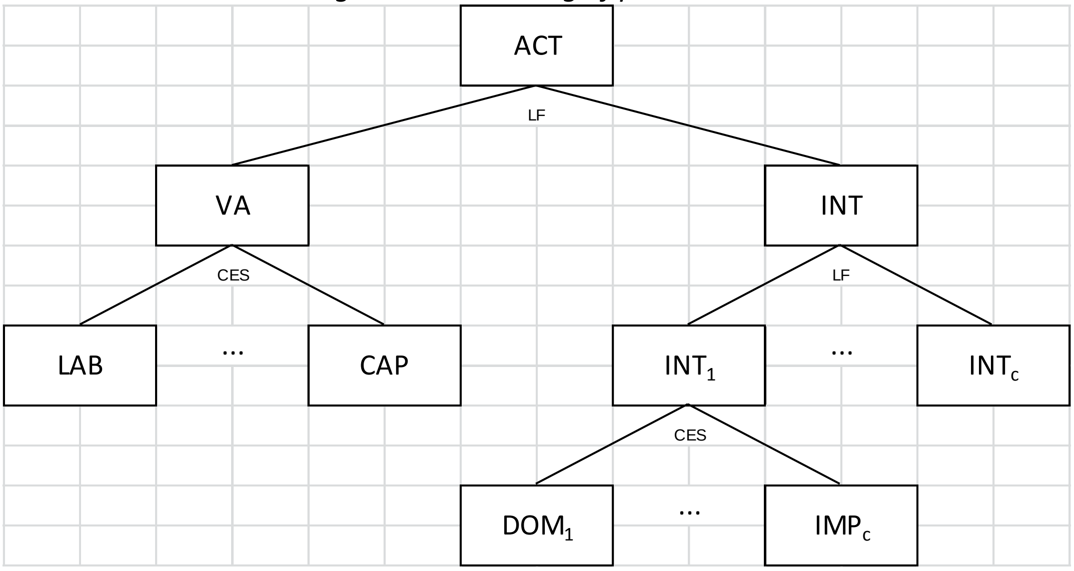
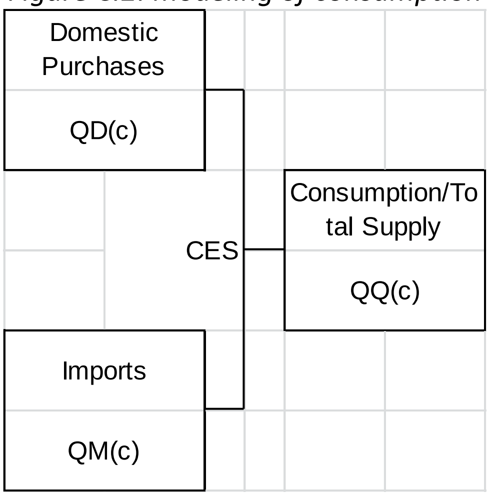


Figure C.2: modeling of consumption



Sets

In the mathematical statement of the model we use the following sets:

A activities,

C commodities (i.e., goods and services),

CD commodities with domestic sales of domestic output

CM imported commodities

CE exported commodities

CT trade and transport commodities (i.e., commodities related to the provision of distribution margins),

F factors,

FNPROX factors without proximity-based sectoral reallocation,

FPROX factors with proximity-based sectoral reallocation,

INS institutional sectors,

INSD domestic institutions,

INSDNG domestic non-government institutions, and

H households.

Besides, the following notation is used:

endogenous variables = upper-case Latin letters;

exogenous variables = upper-case Latin letters with a bar on top – usually as part of the model "closure rule" (see below);

parameters = lower-case Latin letters or lower case Greek letters; and

set indices = lower-case Latin letters as subscripts to variables and parameters.

In addition, variable names for quantities and prices start with Q and P, respectively.

Variables

CPI consumer price index

DPI index for domestic producer prices (PDS-based)

EG	total current government expenditure
EH_h	household consumption expenditure
EXR	exchange rate (dom. currency per unit of foreign currency)
$GDAJ$	government demand scaling factor
$IADJ$	investment scaling factor (for fixed capital formation)
MPS_i	marginal propensity to save for dom non-gov inst *insdng*
$MPSADJ$	savings rate scaling factor
PA_a	output price of activity *a*
PDD_c	demand price for commodity *c* produced and sold domestically
PDS_c	supply price for comm *c* produced and sold domestically
PE_c	export price for *c* (domestic currency)
PM_c	import price for *c* (domestic currency)
PQ_c	composite commodity price for *c*
PX_c	producer price for commodity *c*
QA_a	level of activity *a*
QD_c	quantity sold domestically of domestic output *c*
QE_c	quantity of exports for commodity *c*
$QF_{f,a}$	quantity demanded of factor f from activity *a*
QFS_f	supply of factor *f*
QG_c	quantity of government demand for commodity *c*
$QH_{c,h}$	quantity consumed of commodity *c* by household *h*
$QINT_{c,a}$	quantity of commodity *c* as intermediate input to activity *a*

$QINV_c$	quantity of investment demand for commodity *c*
QM_c	quantity of imports of commodity *c*
QQ_c	quantity of goods supplied domestically (composite supply)
QT_c	quantity of trade and transport demand for commodity *c*
QX_c	quantity of domestic output of commodity *c*
$REXR$	real exchange rate
$GSAV$	government savings
$FSAV$	foreign savings (foreign currency)
$INSSAV_i$	savings of (domestic non-government) institution *insdng*
$TRII_{i',i}$	transfers to institution *i* from domestic non-gov institution *i'*
$WALRAS$	to check walras law
WF_f	average price of factor *f*
$WFDIST_{f,a}$	wage distortion factor for factor f in activity *a*
YI_i	income of (domestic non-government) institution *insdng*
$YIF_{i,f}$	income of institution ins from factor *f*
YF_f	income of factor *f*
YG	government revenue
$QFTR_{f,a,a'}$	quantity of factor *f* located in a allocated to *a'*
$SHRQFA_{f,a}$	share of factor *f* located in activity *a*
$UERATFA_{f,a}$	unemployment rate for fac-act combination *f*-*a* (in fprox)
$WFAD_{f,a}$	wage of *f* in destination act *a* (before wfdist adjustment)
$WFAS_{f,a}$	wage of f in initial location act *a* (before wfdist adjustment)

Parameters

$shif_{i,f}$	share for inst ins in the income of factor *f*
$shii_{i',i}$	share of inst *i*' in post-tax post-sav income of inst *i*
$trnsfr_{ac,i}$	transfers from insp ($i \in \{gov, row\}$) to ins or factor ($ac \in \{i, f\}$)
$\overline{mps}_i$	marginal propensity to save for dom non-gov inst *insdng*
$\overline{qg}_c$	base-year qnty of government demand for commodity *c*
$\overline{rgfcf}_{inv}$	base-year real gross fixed capital investment in capital stock inv
$cc_{inv,c}$	qnty of commodity c per unit of investment in inv
ta_a	rate of tax on producer gross output value
tva_a	rate of (activity-based) value added tax
tq_c	rate of sales tax
ty_i	rate of direct tax on dom inst *i*'
te_c	export tax rate for commodity *c*
tf_f	rate of direct tax on factors (soc sec tax)
tm_c	import tariff rate for commodity *c*
pwe_c	export price for *c* (foreign currency)
pwm_c	import price for *c* (foreign currency)
$qdstk_c$	changes in inventories
$cwts_c$	weight of commodity *c* in the CPI
$dwts_c$	domestic sales price weights
$icd_{c,c'}$	trade and transport input of *c* per unit of commodity *c*’ produced and sold domestically

$ice_{c,c'}$ trade and transport input of *c* per unit of comm *c'* exported

$icm_{c,c'}$ trade and transport input of *c* per unit of comm *c'* imported

Technological Parameters

$\delta^{va}_{f,a}$ share parameter for CES activity VA production function

ϕ^{va}_{a} shift parameter for CES activity VA production function

σ^{va}_{a} elasticity of substitution between factors

ρ^{va}_{a} exponent in the value added production function for *a*

$\theta_{a,c}$ yield of output *c* per unit of activity *a*

$ica_{c,a}$ intermediate input *c* per unit of aggregate intermediate

iva_{a} aggregate value added coefficient

$inta_{a}$ aggregate intermediate input coefficient

$\alpha_{c,h}$ share of household consumption spending on commodity *c*

δ^{m}_{c} Armington function share parameter for imports commodity *c*

δ^{dd}_{c} Armington function share parameter for domestic commodity *c*

ϕ^{q}_{c} Armington function shift parameter for commodity *c*

σ^{q}_{c} elasticity of substitution between dom goods and imports for *c*

ρ^{q}_{c} Armington function exponent for commodity *c*

δ^{e}_{c} CET function share parameter for exports commodity *c*

δ^{ds}_{c} CET function share parameter for domestic commodity *c*

ϕ^{x}_{c} CET function shift parameter for commodity *c*

σ^{x}_{c} elasticity of transformation between domestic sales and exports for *c*

ρ_c^x CET function exponent for commodity *c*

Equations

In this section of the document we describe the different blocks of the model, using circular flow scheme of economics; i.e., starting with production and factor incomes, income distribution, international trade, final demand, and macro closure. Towards the end, we provide a discussion on the model dynamics. To simplify, we do not provide details on the available (domestic and foreign) financing options for the government.

Production

Equations (PF1)-(PF3) represent the first order conditions of the optimization problem solved by the representative firm in each industry or activity (i.e., cost minimization/profit maximization). The value added production technology is CES (Constant Elasticity of substitution). The remuneration to factor *f* not in *FPROX* paid by the activity *a* is computed as $WF_f WFDIST_{f,a}$, where $WFDIST_{f,a}$ is a "distortion" factor that allows modeling cases in which the factor remuneration differs across activities.[14] As discussed in Lofgren et al. (2002), this formulation allows to easily select among alternative closures (i.e., mechanisms to equalize supply and demand) in the factor markets.[15] Equation (PF3) applies to factors in FPROX; i.e., factors with proximity-based sectoral movements (see below).

Equation (FP4) computes sectoral total factor productivity (TFP) as a function of (a) an exogenous component, and (b) the size of the public infrastructure capital stocks. Thus, an increase in the provision of public infrastructure of type *invginf* (e.g., roads) would have positive impacts on sectoral TFP, more or less strong depending on the value assigned to the $tfpelas_{a,invg}$ elasticity parameter. In equation (FP7), variable KG_{invg}^{00} refers to the public capital stock in sector *invg* in the base year. In other words, our model assumes that, based

[14] In this presentation we assume that its value is constant for all factors except capital (see below).

[15] Besides, for the factors considered as specific, equation (PF3) is interpreted as an equilibrium condition between factor supply and demand.

on available empirical evidence, that public infrastructure has positive externalities on sectoral TFP. For model calibration, the initial public capital stock can be estimated through alternative methods; for example, based on recent data for public investments.

In equation (PF5), individual intermediate inputs are a fixed share of output, where the $ica_{c,a}$ parameters represent Leontief technical coefficients.

(PF1) $$QA_a = TFP_a \phi_a^{va} \left(\sum_f \delta_{f,a}^{va} QF_{f,a}^{-\rho_a^{va}} \right)^{\frac{-1}{\rho_a^{va}}} \qquad a \in A$$

(PF2) $$QF_{f,a} = \left(\frac{PVA_a}{WF_f \overline{WFDIST}_{f,a}} \right)^{\sigma_a^{va}} \left(\delta_{f,a}^{va}\right)^{\sigma_a^{va}} \left(TFP_a \phi_a^{va}\right)^{\sigma_a^{va}-1} QA_a \qquad f \in FNPROX$$

(PF3) $$QF_{f,a} = \left(\frac{PVA_a}{WFAD_{f,a}} \right)^{\sigma_a^{va}} \left(\delta_{f,a}^{va}\right)^{\sigma_a^{va}} \left(TFP_a \phi_a^{va}\right)^{\sigma_a^{va}-1} QA_a \qquad f \in FPROX, a \in A$$

(PF4) $$TFP_a = tfpexog_a CALTFP_a \prod_{invg \in INVGINF} \left(\frac{QKG_{invg}}{QKG_{invg}^{00}} \right)^{tfpelas_a} \qquad a \in A$$

(PF5) $$QINT_{c,a} = ica_{c,a} QA_a \qquad c \in C, a \in A$$

Equation (PF6) computes the production of each product on the basis of the $\theta_{a,c}$ parameter, which represents the production of product c per unit produced of activity a. Thus, similar to the supply and use tables, our model differentiates between activities and commodities/products. In addition, an activity can produce more than commodity and the same commodity may be produced by more than one activity.

(PF4) $$QX_c = \sum_{a \in A} \theta_{a,c} QA_a \qquad c \in C$$

Prices

Equation (PR1) implicitly defines the price of value added, as all other variables in that equation are determined elsewhere in the model. For each activity, the price of its intermediate input composite per unit of output is a weighted average of the prices of each of the commodities that is demanded as an intermediate input, with $ica_{c,a}$ as weights.

(PR1) $$PA_a(1-ta_a)=PVA_a+\sum_{c\in C}PQ_c ica_{c,a} \qquad a\in A$$

The price of each activity is a weighted average of the prices of the commodities it produces (equation (PR2)).

(PR2) $$PA_a=\sum_{c\in C}\theta_{a,c}PX_c \qquad a\in A$$

Equations (PR3) and (PR4) define domestic prices of exports (PE) and imports (PM), respectively. It is assumed that the modeled economy is small; thus, world prices for exports and imports are given (pwe and pwm; also, see below). The government can collect tariffs on imports and taxes on exports, at rates tm(c) and te(c), respectively. Besides, the model also considers trade and transport margins applied to exports and imports; i.e., ice(ct,c) and icm(ct,c) represent the quantity of trade/transport commodity *ct* per unit of exports and imports of commodity *c*, respectively.

(PR3) $$PE_c=(1-te_c).EXR.pwe_c-\sum_{c'\in CT}PQ_{c'}ice_{c',c} \qquad c\in C$$

(PR4) $$PM_c=(1+tm_c).EXR.pwm_c+\sum_{c'\in CT}PQ_{c'}icm_{c',c} \qquad c\in C$$

Equation (PR5) computes the demand price of the domestic product, by adding to its supply price the corresponding trade and transport margin.

(PR5) $$PDD_c=PDS_c+\sum_{c'\in CT}PQ_{c'}icd_{c',c} \qquad c\in C$$

Incomes and Savings

FACTORS. Equations (YF1) and (Y2) compute total income of factor *f* with and without proximity-based sectoral reallocation, respectively. The first term on the right hand side corresponds to the total factor payments from activities. Besides, factor *f* can receive transfers from the rest of the world.[16] In turn, equation (YF3) computes the income received by each institution for being the owner of factor *f*.

(YF1) $$YF_f = \sum_{a \in A} WFAD_{f,a} \overline{WFDIST}_{f,a} QF_{f,a} + trnsfr_{f,row} EXR \qquad f \in FPROX$$

(YF2) $$YF_f = \sum_{a \in A} WF_f \overline{WFDIST}_{f,a} QF_{f,a} + trnsfr_{f,row} EXR \qquad f \in FNPROX$$

(YF3) $$YIF_{i,f} = shif_{i,f} YF_f \left(1 - tf_f\right) \qquad i \in INS,\ f \in F$$

DOMESTIC NON-GOVERNMENT INSTITUTIONS. The income of institution *i* (for example, households) is the sum of four elements (see equation (H1)): (1) factor income; (2) transfers from the government, indexed to the consumer price index (CPI); (3) transfers from rest of the world (i.e., remittances), exogenous in foreign currency; and (4) transfers from other domestic non-government institutions. Equation (H2) computes the marginal propensity to save for the domestic non-government institutions. Initially, $MPSADJ$ is equal to one.[17] Equation (H3) computes the value of savings for each domestic non-government institution in the model. Equation (H4) computes the consumption spending by the households as their income net of transfers to other institutions, savings, and direct taxes.

(H1) $$YI_i = \sum_f YIF_{i,f} + trnsfr_{i,gov} \overline{CPI} + trnsfr_{i,row} EXR + \sum_{i' \in insdng} TRII_{i,i'} \qquad i \in INSDNG$$

(H2) $$MPS_i = \overline{mps_i}\, \overline{MPSADJ} \qquad i \in INSDNG$$

(H3) $$INSSAV_i = MPS_i \left(1 - ty_i\right) YI_i \qquad i \in INSDNG$$

(H4) $$EH_h = \left(1 - \sum_{i \in INS} shii_{i,h}\right)\left(1 - MPS_h\right)\left(1 - ty_h\right) YI_h \qquad h \in H$$

[16] Note that the *trnsfr* parameter is expressed in foreign currency units.

[17] Besides, in this presentation it is assumed that $MPSADJ$ is an exogenous variable.

GOVERNMENT. Equation (G1) computes government income as the sum of four elements: (1) tax collection, (2) transfers from the rest of the world, (3) transfers from other domestic institutions, and (4) factor income. Note that transfers from the rest of the world are multiplied by the exchange rate so that they are expressed in national currency. The government uses its income to provide goods and services and make transfers to other institutions (equation (G2)). Equation (G3) computes government savings as the difference between current income (YG) and current spending (EG).

(G1)
$$\begin{aligned} YG = & \sum_{i \in INSDNG} ty_i YI_i \\ & + \sum_{c \in C} tq_c \left(PDD_c QD_c + PM_c QM_c \right) \\ & + \sum_{c \in C} tm_c EXR.pwm_c QM_c \\ & + \sum_{c \in C} te_c EXR.pwe_c QE_c \\ & + \sum_{a \in A} ta_a PA_a QA_a \\ & + \sum_{f \in F} tf_f YF_f \\ & + EXR.trnsfr_{gov,row} \\ & + \sum_{i \in INSDNG} TRII_{gov,i} \\ & + \sum_{f \in F} YIF_{gov,f} \end{aligned}$$

(G2)
$$EG = \sum_{c \in C} PQ_c QG_c + \sum_{i \in INSDNG} trnsfr_{i,gov} \overline{CPI} + trnsfr_{row,gov} EXR$$

(G3)
$$GSAV = YG - EG$$

REST OF THE WORLD. The rest of the world is represented through the current account of the balance of payments, expressed in foreign currency (equation (RW1)). The left (right) hand side shows the inflows (outflows) of foreign exchange.

(RW1)
$$\begin{aligned} & \sum_{c \in C} pwe_c QE_c + \sum_{i \in INSD} trnsfr_{i,row} + \sum_{f \in F} trnsfr_{f,row} + \overline{FSAV} = \\ & \sum_{c \in C} pwm_c QM_c + trnsfr_{row,gov} + \sum_{f \in F} \frac{YIF_{row,f}}{EXR} + \sum_{i \in INSDNG} \frac{TRII_{row,i}}{EXR} \end{aligned}$$

TRANSFERS. The model provides a detailed treatment for transfers. For instance, transfers from a domestic non-government institution *i* (e.g., households, enterprises, others) to institution *i*' are modeled as an exogenous share of the income of institution *i* net of savings and direct taxes (equation (TR1)). In case enterprises are present in the SAM as an institution, it is assumed that they can save and pay direct taxes, but do not demand commodities. In practice, enterprises usually receive most of the capital income to distribute it among the other institutions, such as households and the rest of the world.

(TR1) $TRII_{i,i'} = shii_{i,i'}(1 - MPS_{i'})(1 - ty_{i'})YI_{i'}$ $\qquad i \in INS, i' \in INSDNG$

International Trade

IMPORTS. On the consumption side, and following the Armington (1969) assumption, we assume that products are differentiated based on their country of origin (i.e., tea from Ugandan tea is different from Indian tea). Consequently, it is possible to consider two-way trade (i.e., the same product is exported and imported simultaneously). To model the imperfect substitution between domestic and imported products, we use a CES function (equation (IM1)).[18] Equation (IM2) is the tangency condition that determines the domestic/imported mix of total supply/demand for each product. Equation (IM3) computes the price of the composite product QQ_c as a weighted average of the domestic and imported varieties of commodity c. The sales tax is imposed on the composite product; notice that the tax base excludes the tax. For products that are only bought domestically or that are only imported, equation (IM1) is replaced with equation (IM1') at the same time that equation (IM2) is excluded from the model.

(IM1) $QQ_c = \phi_c^q \left(\delta_c^m QM_c^{-\rho_c^q} + \delta_c^{dd} QD_c^{-\rho_c^q} \right)^{-\frac{1}{\rho_c^q}}$ $\qquad c \in CM \cup CD$

(IM1') $QQ_c = QM_c + QD_c$ $\qquad (c \in CM \wedge c \notin CD) \vee (c \in CD \wedge c \notin CM)$

[18] The elasticity of substitution between domestic purchases and imports is $\sigma_c^q = 1/(1 + \rho_c^q)$.

(IM2) $$\frac{QM_c}{QD_c} = \left(\frac{PDD_c}{PM_c} \frac{\delta_c^m}{\delta_c^{dd}} \right)^{\frac{1}{1+\rho_c^q}} \qquad c \in CM \cup CD$$

(IM3) $$PQ_c QQ_c = \left(PDD_c QD_c + PM_c QM_c \right)\left(1 + tq_c\right) \qquad c \in C$$

EXPORTS. On the production side, production can be sold in the domestic market and/or exported to the rest of the world. In terms of modeling, we use a CET (Constant Elasticity of Transformation) function (equation (EX1)).[19] Equation (EX2) corresponds to the first order conditions of the profit maximization problem solved by the producer. Equation (EX3) is the zero profit condition for the production of commodity *c*, from where price PX_c is obtained. For products that are only sold domestically or are only exported, equation (EX1) is replaced by equation (EX1') and equation (EX2) is excluded from the model.

(EX1) $$QX_c = \phi_c^x \left(\delta_c^e QE_c^{\rho_c^x} + \delta_c^{ds} QD_c^{\rho_c^x} \right)^{\frac{1}{\rho_c^x}} \qquad c \in CE \cup CD$$

(EX1') $$QX_c = QE_c + QD_c \qquad (c \in CE \wedge c \notin CD) \vee (c \in CD \wedge c \notin CE)$$

(EX2) $$\frac{QE_c}{QD_c} = \left(\frac{PE_c}{PDS_c} \frac{\delta_c^{ds}}{\delta_c^e} \right)^{\frac{1}{\rho_c^x - 1}} \qquad c \in CE \cup CD$$

(EX3) $$PX_c QX_c = PDS_c QD_c + PE_c QE_c \qquad c \in C$$

Final Consumption

Household consumption expenditure is distributed across commodities according to a Cobb-Douglas utility function (equation (CF1)). Note that households are the only domestic non-government institution that records final consumption. Equation (CF2) computes the investment demand of commodity *c*. It is assumed that the commodity composition of investment type inv (i.e., gov/non-gov) is exogenous – see parameter cc(inv,c). Thus, if there is an increase in investment, the investment demand for all goods and services will increase

[19] The elasticity of transformation between domestic sales and exports is $\sigma_c^x = 1/\left(\rho_c^x - 1\right)$.

in the same proportion.[20] Equation (CF3) computes the government consumption of commodity *c*. It is assumed that the commodity composition of government consumption is also fixed at its initial values. Initially, variable $GADJ$ is equal to one. Equation (CF4) is the total demand for commodities that provide trade and transport margins; the demand for such commodities is linked to domestic products, imports and exports.

(CF1) $$QH_{c,h}PQ_c = \alpha_{c,h}EH_h \qquad c \in C, h \in H$$

(CF2) $$QINV_c = \sum_{inv \in INV} cc_{inv,c} RGFCF_{inv} \qquad c \in C$$

(CF3) $$QG_c = \overline{qg}_c \overline{GADJ} \qquad c \in C$$

(CF4) $$QT_c = \sum_{c' \in C} icd_{c,c'} QD_{c'} + \sum_{c' \in C} icm_{c,c'} QM_{c'} + \sum_{c' \in C} ice_{c,c'} QE_{c'} \qquad c \in CT$$

Unemployment

Equation (U1) is the wage curve for factor f (see Blanchflower and Oswald 1994). It is assumed that there is a negative relation between the real wage and the unemployment rate, as the value of the phillips parameter is negative. In fact, Blanchflower and Oswald (2005) report a value for the unemployment-elasticity of wage close to -0.1 for a large number of countries. Note that the wage curve is consistent with several stories to explain the presence of unemployment for the labor market, such as efficiency wages, unions with bargaining power, among others.

$$\frac{WF_f}{CPI} = \frac{WF_f^{00}}{CPI^{00}} \left(\frac{UERAT_f}{UERAT_f^{00}} \right)^{\eta_f^{wf}} \qquad \text{(U1)}$$

Equilibrium Conditions

FACTOR MARKETS. Equation (EQ1) is the equilibrium condition in the market for factor f. As will be shown, this model presentation assumes that all factor supplies are exogenous.

[20] This presentation assumes that investment is considered as an endogenous variable; see below the discussion of macroeconomic closure rule.

However, the supply of each factor (QFS_f) can be exogenous or endogenous depending on the selected closure rule.

(EQ1) $$\overline{QFS}_f\left(1-UERAT_f\right)=\sum_{a\in A}QF_{f,a} \qquad f\in FNPROX$$

COMMODITY MARKETS. Equation (EQ2) is the equilibrium condition between supply and demand for each commodity. Total supply, composed of domestic and imported varieties, is used for household consumption, intermediate consumption, investment, government consumption and changes in inventories.

(EQ2) $$\sum_h QH_{c,h}+\sum_a QINT_{c,a}+QINV_c+QG_c+qdstk_c+QT_c=QQ_c \qquad c\in C$$

SAVINGS-INVESTMENT. Equation (EQ3) is the savings-investment balance; three are the institutions that contribute to total savings: domestic non-government institutions (i.e., households and enterprises), government, and the rest of the world. The variable WALRAS must be zero in equilibrium.

(EQ3) $$\begin{gathered}\sum_{c\in C}PQ_c\left(QINV_c+qdstk_c\right)+WALRAS=\\ \sum_{i\in INSDNG}INSSAV_i+GSAV+EXR.\overline{FSAV}\end{gathered}$$

Factors with Proximity-Based Sectoral Reallocation

Equation (X1) computes the share of factor *f* belonging to activity *a* in any given time period other than the first one; it is equal to the share of activity *a* in the employment of factor *f*. Equation (X2) applies to factors that are subject to equilibrium conditions by f-a; the related variable is $WFAS_{f,a}$, which reflects the (relative) scarcity value of factor f in activity a (this wage is per physical unit of factor *f*). Equations (X3) shows the allocation of factor *f* to destination *a'*. Thus, this equation defines the effective quantity of each factor *f* employed by destination activity *a'* as the sum of the productivity-adjusted physical quantities of factor *f* from different activities *a*; the related variable $WFAD_{f,a}$ represents the scarcity wage of factor *f* in destination *a'* (this wage is per effective unit). Equation (X4) is a constraint that links the wage of factor *f* in location *a* and destination *a*'; this equation is a mixed-complementarity relationship with the variable QFTR. In other words, if factor *f* located in *a* is used in *a'* [i.e., $QFTR_{f,a,a'} > 0$], then [*WFAS*: wage of *f* in location a (per physical unit)] is equal to [*WFAD*: wage of *f* in destination a' (per effective unit)] TIMES [prox: effective share of physical factor] related variable: $QFTR_{f,a,a'}$ = quantity of factor f transferred from a to ap. Equation (X5) is the wage curve that can be for each f-a combination.

(X1) $$SHRQFA_{f,a} = \frac{\sum_{a' \in A} QFTR_{f,a,a',-1}}{\sum_{a' \in A} \sum_{a'' \in A} QFTR_{f,a',a'',-1}} \qquad f \in FPROX, a \in A$$

(X2) $$QFS_f \left(1 - UERATFA_{f,a}\right) SHRQFA_{f,a} = \sum_{a'} QFTR_{f,a,a'} \qquad f \in FPROX, a \in A$$

(X3) $$\sum_{a \in A} proxf_{f,a,a'} QFTR_{f,a,a'} = QF_{f,a'} \qquad f \in FPROX, a' \in A$$

(X4) $$WFAS_{f,a} = WFAD_{f,a'} proxf_{f,a,a'}$$

(X5) $$\frac{WFAS_{f,a}}{CPI} = \frac{WFAS_{f,a}^{00}}{CPI^{00}} \left(\frac{UERATFA_{f,a}}{UERATFA_{f,a}^{00}} \right)^{\eta_f^{wf}}$$

Miscellaneous

Equation (MIS1) defines the consumer price index as a weighted average of the composite commodity prices (PQ); the weights are the shares of each commodity in private (i.e., household) consumption. In this presentation CPI is the model numeraire (see below). Equation (MIS2) defines the producer domestic price index as a weighted average of the prices of domestic output sold in the domestic market. Finally, equation (MIS3) defines the real exchange rate, as the ratio between the nominal exchange rate and the producer domestic price index.

$$\sum_{c \in C} PQ_c cwts_c = \overline{CPI} \qquad \text{(MIS1)}$$

$$\sum_{c \in C} PDS_c dwts_c = DPI \qquad \text{(MIS2)}$$

$$REXR = \frac{EXR}{DPI} \qquad \text{(MIS3)}$$

Investment by Destination

Lastly, this group of equations presents the model dynamics. Specifically, the mechanisms used to assign each period private and public investment among sectors are presented. As will be shown, a distinction is made between private and public capital stocks. For the non-government sector, investment in each period increases the capital stock available in the next period. Then, we need to determine how the new capital is distributed among industries. In our model, for private investment (i.e., households and/or enterprises) we assume that the new capital is distributed across activities based on sectoral differences in capital rates of return. Thus, sectors with a relatively higher (lower) capital rate of return receive a relatively larger (smaller) share of the new capital. For the government, investment can be determined in two alternatives ways: as a policy variable (i.e., exogenously), or as a residual to balance the government budget.

Equation (D1) computes the price of one unit of private or public capital; the new capital good is assembled using a fixed coefficient production function. Equation (D2) computes, for each investment category (private/public) the real gross fixed capital formation, which refers to the quantity of new units of the capital good that will be available to produce the next period. Equation (D3) computes the average (private) capital rate of return, as the ratio between total capital income and total capital stock. Equation (D4) computes, following the explanation on the previous paragraph, the investment by destination sector. The κ parameter, which varies between zero and one, measures the degree of capital mobility among productive sectors. When κ is zero, investment is distributed among sectors only based on the initial share of each sector in the total capital stock. When κ is positive, investment is distributed among sectors also based on the relative capital returns. Equation (D5) shows how sectoral (private) capital stocks are updated. Finally, equation (D6) updates the public capital stocks of period t trhough public investment from period t-1.

(D1) $$PK_{inv,t} = \sum_{c \in C} capcomp_{inv,c} PQ_{c,t}$$

(D2) $$RGFCF_{inv,t} = rgfcf_{inv,t} IADJ_t$$

(D3) $$AW_{f,t} = \frac{\sum_{a \in A} WF_{f,t} WFDIST_{f,a,t} QF_{f,a,t}}{\sum_{a \in A} QF_{f,a,t}}$$

(D4) $$IND_{k,a,t} = RGFCF_{invng,t} \frac{QF_{k,a,t}}{\sum_{a' \in A} QF_{k,a',t}} \left(1 + \kappa \left(\frac{WF_{k,t} WFDIST_{k,a,t}}{AW_{k,t}} - 1\right)\right)$$

(D5) $$QF_{k,a,t} = QF_{k,a,t-1}\left(1 - deprcap_k\right) + IND_{k,a,t-1}$$

(D6) $$QKG_{invg,t} = QKG_{invg,t-1}\left(1 - deprcap_{gov}\right) + RGFCF_{invg,t-1}$$

In addition, model dynamics require the imposition of growth rate for the other factor endowments, the minimum consumption of households, and transfers model through the $\overline{tr}_{ac,i}$ parameter.

Closure Rule

It can be shown that the model presented has more variables than equations. Consequently, depending on the variables that are exogenized, we obtain a different macroeconomic behavior. Specifically, we need to select the mechanisms to balance factor markets (equation (EQ1)), government budget (equation (G3)), savings and investment (equation (EQ3)), and the current account of the balance of payments (equation (RW1)). In the main text, the closure selected for simulations is discussed.

APPENDIX C: SENSITIVITY ANALYSIS