

Online supplement: Model description and summary tables of model parameters, variables, and blocks of equations (Annex 1, Annex 2 and Annex 3)

Model description

The version of the Static General Equilibrium (STAGE) model used in this study is a member of the class of Computable General Equilibrium (CGE) models that are descendants of the approach to CGE modelling described by Dervis et al. (1982). The base model is documented in detail in McDonald (2007), while versions closer to the one adapted for this study are presented in Aragie (2014). While the Social Accounting Matrix (SAM) determine the agents that can be included within the model, and the transactions recorded in the SAM identify the transactions that took place, the model is defined by a series of behavioural and non-behavioural relationships. The behavioural relationships in this model are a mix of non-linear and linear relationships that govern how agents captured in the model respond to exogenously determined changes in the model's parameters and variables.

The model used follows the standard neoclassical specification of trade focused CGE models. Each sector produces a composite commodity that can be transformed according to a Constant Elasticity of Transformation (CET) function into a commodity sold on the domestic market or exported. The optimal allocation of domestically produced commodities between the domestic and export markets is determined by relative prices in these markets. Likewise, the Constant Elasticity of Substitution (CES) function determines the substitutability between imported and domestically produced goods consumed locally, subject to relative prices of imports and locally produced goods. While a small-country assumption, i.e. a price-taker country in the import and export markets, is considered in this study, the model can be specified for a large country where selected export commodities can be deemed to face downward-sloping export demand functions.

The model used in this study includes a multi-stage production function for domestic activities. At the lowest strata of the production nest, land is combined with irrigation to form a *land-irrigation* aggregate. This aggregate input is then combined with fertilizer to form a *land-irrigation-fertilizer* aggregate input. This way of aggregating land, irrigation and fertilizer at various stages helps to capture the different rates of substitution among these inputs and helps to account for the close substitutability between land and irrigation inputs. Meanwhile, labour is aggregated by skill levels

and region at the very lowest stages of the production structure. This aggregate labour factor is then combined with agricultural and non-agricultural capital to form an aggregate non-land value-added input. At the very top of the production nest, the aggregate value-added inputs are combined with intermediates to generate an output by activity.

Total domestic demand for commodities consists of intermediate demand, household, enterprise, government, investment final demand and stock change. Households' consumption is assumed to follow a two-stage consumption nesting structure such that households' demand for commodities can reflect the source of commodities as defined in the SAM. At the bottom of the consumption nest is a CES demand system where close commodity types (e.g. cereals) are combined into composite commodities subject to relative prices. Consumers decide on the optimal combination of these two types of commodities based on their relative prices subject to the imperfect substitution elasticity defined as part of the CES function. At the top of the nest, consumers maximise utility from the consumption of a set of composite commodities (from the lower nest) subject to their budget constraints and the Linear Expenditure System (LES) demand system derived from the Stone-Geary utility function.

Annex 1

Sets, parameters, and variables in the modified STAGE model (selected)

Sets and sub-sets	Description	Alias
c	Commodities	Each set has an <i>alias</i> that has the same membership as the corresponding basic set. The notation follows the addition of a ‘ <i>p</i> ’ suffix to the set label. Example: the alias for c is cp .
cag	Aggregate commodities	
$cfert, cirriga$	Fertilizer and irrigation commodities in set c	
a	Activities	
m	Margins	
f	Natural factors (labour, land, etc.)	
f_2	Aggregate factors	
$instw$	Institutions including households, enterprises, etc.	
h	Households	
g	Government	
e	Enterprises	
i	Investment	
w	The rest of the world	
Parameters (lower-case letters)	Description	Source
$ioqttq_{m,c}$	Quantity of trade and transport services per unit of commodity delivered	Model calibration
$betacp_{cag,c}$	Marginal budget shares for CES price aggregation	Model calibration
$beta_{cag,h}$	Marginal budget shares for LES demand functions	Model calibration
$beta2_{cag,cp,h}$	Marginal budget shares for CES demand functions	Model calibration
$qcdconst_{cag,h}$	Subsistence demand by household h	Model calibration
$ioqintqx_a$	Intermediate quantity per unit of QX_a for Leontief aggregate	Model calibration
$dstocconst_c$	Change in stock of commodity c	Model calibration

Annex 1 (*continued*)

Parameters (<i>continued</i>)	Description	Source
$\delta_a^x, \delta_a^{vx}$	Share parameters in the QX_a and QVA_a production functions	Model calibration
$\delta_a^{vlix}, \delta_a^{vlx}, \delta_a^{vlx}$	Share parameters in the $QVLK_a$, QVL_a and $QVLI_a$ production functions	Model calibration
$\delta_{cfert,a}^{vf}, \delta_{cirriga,a}^{vi}$	Share parameters in the QVF_a and QVI_a production functions	Model calibration
ac_c, at_c	Shift parameters in the CES and CET in trade	Model calibration
δ_c, ρ_c	Share parameters in the CES and CET in trade	Model calibration
$rhocp_{cag}$	Substitution parameters in the CES price aggregate	Assumption
$rhocd_{cag,h}$	Substitution parameters in the CES demand system	Assumption
$rhoc_c, rhot_c$	Substitution parameters in the CES and CET in trade	Assumption
$rhoc_a^x, rhoc_a^{vx}$	Substitution parameters in the QX_a and QVA_a production functions	Assumption
$rhoc_a^{vlix}, rhoc_a^{vlx}, rhoc_a^{vlix}$	Substitution parameters in the $QVLK_a$, QVL_a and $QVLI_a$ production functions	Assumption
$rhoc_a^{vf}, rhoc_a^{vi}$	Substitution parameters in the QVF_a and QVI_a production functions	Assumption
Variables (upper-case letters)	Description	
PQS_c, PQD_c, PQD_{cag}	Supply and consumer prices of commodity c and composite consumer prices of cag	
PM_c, PD_c, PE_c	Prices of imported, domestically supplied and exported commodities	
ER, PWE_c	Exchange rate and world price of export commodity c	
PTT_m	Price of trade and transport margin	
QM_c, QD_c, QE_c	Quantities of imported, domestically supplied and exported commodities	
QQ_c	Composite supply of commodity c	
$QCD_{c,h}$	Household h consumption of commodity c in the lower consumption nest	

Annex 1 (continued)

Variables (continued)	Description
$QCD_{cag,h}$	Household h consumption of commodity cag in the top consumption nest
QXC_c	Domestic production of commodity c
$QVA_a, QINT_a, QX_a$	Value added, intermediate, and total output
$QVLK_a, QVL_a$	Non-land aggregate and <i>land_irrigation_fertilizer</i> aggregate
$QVLA_a, QVLI_a$	Land aggregate and irrigation_land aggregate
QVF_a, QVI_a	Fertilizer aggregate and irrigation aggregate
$QINTD_{c,a}$	Quantity of intermediate demand of commodity c by activity a
$QTTD_c$	Quantity of commodity c required to produce a unit of margins service
$QENTD_{c,e}, QGD_c, QINVD_c$	Enterprise (e), government and investment demand for commodity c
$YH_h, HEXP_h$	Income and expenditure of household h
SHH_h, TYH_h	Saving and tax rate by household h
TS_c, TEX_c	Sales and excise taxes on commodity c
$TV_c, TV02_{cag}$	Value-added taxes on natural commodity c and composite commodity cag
$HOHO_{hp,h}$	Inter-household transfers
$ADX_a, ADVA_a$	Shift/efficiency parameters for QX_a and QVA_a production functions
$ADVLK_a, ADVLI_a$	Shift/efficiency parameters for $QVLK_a$ and $QVLI_a$ production functions
$ADFDLK_{f2,a}$	Shift/efficiency parameter for factor and activity specific efficiency at $QVLK_a$
$ADVI_a, ADVL_a, ADVF_a$	Shift/efficiency parameters for and QVI_a, QVL_a and QVF_a production functions
$FSINST_{instw,f}$	Supply of factor f by institution $instw$
$FSSHARE_{instw,f}$	Share of factor f in the factor endowment of institution $instw$
$FD_{f,a}$	Factor demand by activity a
$FD_{f2,a}$	Demand for aggregate factor f_2 by activity a
$UNEMP_{instw,f}$	Unemployment by factor f and institution $instw$
$ADFD_{f,a}$	Shift parameter for factor f and activity a

Annex 2

Equation blocks in the modified STAGE model (selected)

Equations	Description
Commodity price block	
$PQS_c = \frac{PD_c * QD_c + PM_c * QM_c}{QQ_c}$	Composite supply price for commodity c
$PXC_c = \frac{PD_c * QD_c + PE_c * QE_c}{QXC_c}$	Supply price of domestically produced commodity c
$PQD_c = PQS_c * (1 + TS_c + TEX_c) + \sum_m (ioqtq_{m,c} * PTT_m)$	Consumer price for commodity c in domestic markets
$PQD_{cag} = \left(\sum_c betac_{p_{cag,c}} * PQD_c \right)^{-1/rhoc_{p_{cag}}}$	Consumer price for composite commodity cag
Household consumption block	
$HEXP_h = (YH_h * (1 - TYH_h)) * (1 - SHH_h) - \left(\sum_{hp} HOHO_{hp,h} \right)$	Household disposable income
$QCD_{cag,h} * PQD_{cag} * (1 + TV02_{cag}) = \left(PQD_{cag} * qcdconst_{cag,h} * (1 + TV02_{cag}) \right) +$ $beta_{cag,h} * \left(HEXP_h - \sum_{cagp} PQD_{cagp} * qcdconst_{cagp,h} * (1 + TV02_{cagp}) \right)$	LES demand system at the upper level of the consumption nest
$PQD_c * (1 + TV_c) = PQD_{cag} * (1 + TV02_{cag}) * QCD_{cag,h} * \sum_{cp} \left(beta2_{cag,cp,h} * (QCD_{cp,h})^{-rhocd_{cag,h}} \right)^{-1}$	CES demand system at the lower level of the consumption nest

Annex 2 (continued)

Equations (continued)	Description
Production block¹	
$QX_a = ADX_a * \left[\delta_a^x QVA_a^{-\rho_{a,x}} + (1 - \delta_a^x) * QINT_a^{-\rho_{a,x}} \right]^{-\frac{1}{\rho_{a,x}}}$	CES production function for composite output QX_a
$QINT_a = ioqintq_x_a * QX_a$	Leontief technology for intermediate inputs
$QVA_a = ADVA_a * \left[\delta_a^{vx} QVLK_a^{-\rho_{a,vx}} + (1 - \delta_a^{vx}) * QVL_a^{-\rho_{a,vx}} \right]^{-\frac{1}{\rho_{a,vx}}}$	CES function for value added aggregate QVA_a
$QVLK_a = ADVLK_a * \left[\sum_{j2} \delta_a^{vjkx} * ADFDLK_{j2,a} * FD_{j2,a}^{-\rho_{a,vjkx}} \right]^{-\frac{1}{\rho_{a,vjkx}}}$	CES function for non-land aggregate $QVLK_a$
$QVL_a = ADVL_a * \left[\delta_a^{vlix} QVLI_a^{-\rho_{a,vlix}} + (1 - \delta_a^{vlix}) * QVF_a^{-\rho_{a,vlix}} \right]^{-\frac{1}{\rho_{a,vlix}}}$	CES function for <i>land_irrigation_fertilizer</i> aggregate
$QVF_a = ADVF_a * \left[\sum_{cfert} \delta_{cfert,a}^{vf} * QINTD_{cfert,a}^{-\rho_{a,vf}} \right]^{-\frac{1}{\rho_{a,vf}}}$	CES function for fertilizer and the like aggregate QVF_a
$QVLI_a = ADVLI_a * \left[\delta_a^{vlix} QVI_a^{-\rho_{a,vlix}} + (1 - \delta_a^{vlix}) * QVLA_a^{-\rho_{a,vlix}} \right]^{-\frac{1}{\rho_{a,vlix}}}$	CES function for land and irrigation aggregate $QVLI_a$
$QVI_a = ADVI_a * \left[\sum_{cirriga} \delta_{cirriga,a}^{vi} * QINTD_{cirriga,a}^{-\rho_{a,vi}} \right]^{-\frac{1}{\rho_{a,vi}}}$	CES function for irrigation and the like aggregate QVI_a
Trade block	
$QQ_c = ac_c * \left(\delta_c * QM_c^{-\rho_{c,hot_c}} + (1 - \delta_c) * QD_c^{-\rho_{c,hot_c}} \right)^{-\frac{1}{\rho_{c,hot_c}}}$	CES function for domestic supply of commodity c
$QXC_c = at_c * \left(\gamma_c * QE_c^{-\rho_{c,hot_c}} + (1 - \gamma_c) * QD_c^{-\rho_{c,hot_c}} \right)^{-\frac{1}{\rho_{c,hot_c}}}$	CET function for production transformation

¹ There are further production nests for labour aggregate by skill and region, and for land aggregate by region.

Annex 2 (*continued*)

Equations (<i>continued</i>)	Description
Market clearing block	
$FSINST_{instw,f} = FSSHARE_{instw,f} * \sum_a FD_{f,a} + UNEMP_{instw,f}$	Factor market clearing condition
$QQ_c = QTTD_c + QINTD_c + \sum_h QCD_{c,h} + \sum_e QENTD_{c,e} + QGD_c + QINVD_c + dstocconst_c$	Total domestic demand for commodities

Annex 3

Structure of selected accounts in the CGE model for Ethiopia

Commodities: Own consumption: teff, maize and sorghum, wheat and barley, other cereals, pulses, oil seeds, vegetables, root crops, permanent crops, meat and milk, other primary food, processed food, construction, utilities, other services. Marketed commodities: teff, maize and sorghum, wheat and barley, other cereals, pulses, oil seeds, vegetables, root crops, permanent crops, meat and milk, other primary food, processed food, mining and natural resources, beverages, textile, chemical fertilizer, other manufacturing, construction, utilities, irrigation, transport and communication, hotel and restaurant, public services, other services.

Sectors/Activities: Multi-product household activities: drought prone highland households in Tigray, Amhara, Oromia, Somali, Benishangul and Southern Peoples regions; drought prone lowland households in Afar, Somali and Dire-Dawa regions; moisture sufficient lowland households in Benishangul, Southern Peoples and Gambella; moisture sufficient highland households in Amhara, Oromia, Southern peoples and Harari regions; small urban households in Tigray, Afar, Amhara, Oromia, Somali, Benishangul, Southern Peoples and Gambella; big urban households in Tigray, Afar, Amhara, Oromia, Somali, Benishangul, Southern Peoples, Gambella, Harari, Addis Ababa and Dire-Dawa regions. Non-household activities: teff, maize and sorghum, wheat and barley, other cereals, pulses, oil seeds, vegetable, root crops, permanent crops, meat and milk, other primary food, processed food, non-alcoholic beverages, alcoholic beverages, leather and textile, other manufacturing, construction, utilities, irrigation, transport and communication, hotel and restaurant, public services, other services.

Households: Drought prone highland households in rural Tigray, Amhara, Oromia, Somali, Benishangul and Southern Peoples regions; drought prone lowland households in rural Afar, Somali and Dire-Dawa regions; moisture sufficient lowland households in rural Benishangul, Southern Peoples and Gambella; moisture sufficient highland households in rural Amhara, Oromia, Southern peoples and Harari regions; small urban households in Tigray, Afar, Amhara, Oromia, Somali, Benishangul, Southern Peoples and Gambella; big urban households in Tigray, Afar, Amhara, Oromia, Somali, Benishangul, Southern Peoples, Gambella, Harari, Addis Ababa and Dire-Dawa regions.

Note: ‘Cereals’ in the export ban analysis include maize and sorghum, and wheat and barley. The export ban on teff is not considered in the ban analysis in response to the world price shock since the government has always been banning teff export for long.