BAE
Bio-based and Applied Economics

AIEAA
ASSOCIAZIONE ITALIANA DI ECONOMIA AGRARIA E APPLICATA

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Citation: Yalew, A.W., Nechifor, V., & Ferrari, E. (2024). The implications of the Russian invasion of Ukraine for African economies: A CGE analysis for Ethiopia. *Bio-based and Applied Economics* 13(3): 225-243. doi: 10.36253/bae-15364

Received: November 19, 2023
Accepted: March 11, 2024
Published: October 16, 2024

Data Availability Statement: All relevant data are within the paper and its Supporting Information files.

Competing Interests: The Author(s) declare(s) no conflict of interest.

Editor: Francesco Pagliacci, Valentina Raimondi, Luca Salvatici

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The implications of the Russian invasion of Ukraine for African economies: A CGE analysis for Ethiopia

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Abstract. The Russian invasion of Ukraine contributed to soaring world market prices of many commodities with severe repercussions for many African countries. This study examines the implications of the 2022 world market price increases for wheat, fuels, and fertilizers for Ethiopia. Using a computable general equilibrium (CGE) model, the study shows negative impacts on GDP, wage rates, and households' consumption in the country. The effects of fertilizer and petroleum price changes are notable and unequal across production sectors. With increasing import prices of inorganic fertilizers, crop growing activities substitute inorganic fertilizers with animal manure reducing the use of manure as cooking fuel. The effects on urban households are more severe than the effects on rural households. Policies supporting biofuels and biogas digesters may dampen the adverse effects stemming from petroleum price surges.

Keywords: Commodity markets, Trade, CGE, Russia-Ukraine war, Ethiopia
JEL Codes: C68, F10, L66.

1. INTRODUCTION

The Russian invasion of Ukraine and the subsequent war have caused a wide-range of crises with short- and long-term implications to the global economy. The repercussions of the war range from disruption of global commodity markets to long-term effects on the prospects of globalization and geopolitical order (Garicano et al., 2022; Ruta, 2022). The disruptions in the global supply chains increased the synchronization of grain, energy, and fertilizer prices at the global level (Ihle et al., 2022). This resulted in contagion across food and non-food markets which would restrict the ability of consumers to mitigate the adverse effects of food and energy price spikes by resorting to inexpensive alternatives (Ihle et al., 2022). The disruptions in global food, fertilizer and energy markets threaten to further increase the number of poor and malnourished people, especially in developing countries (Guan et al., 2023; Osendarp et al., 2022).

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The type and size of the effects will differ across countries as these are determined by the trade, production and consumption structures, and government responses in different countries (Garicano et al., 2022). It is therefore necessary to understand how the war in Ukraine affects individual economies (Ruta, 2022) to underpin country-specific policy measures increasing the resilience of each economy.

The short- and long- term implications of the war in Ukraine for African countries are worrisome (Badiane et al., 2022; UNCTAD, 2022). From the 107 economies highly exposed to the shocks due the war in Ukraine, 41 are in Africa (UN, 2022a). Since many African countries are net importers of cereals, vegetable oils and fertilizers, the implications of the war to food security are substantial (Badiane et al., 2022). Higher import prices represent negative terms-of-trade for African economies in which poor households face the hardest hit (Arndt et al., 2008). Besides, many African countries have limited fiscal and borrowing capacities to respond to global energy and food market crises, particularly after various spending measures and tightening of monetary policies to cope with and recover from the COVID-19 pandemic crisis.

The effects on Ethiopia are of particular interest (Diao et al., 2022) as it depends almost entirely on imported petroleum and inorganic fertilizers (Mengistu et al., 2019); the two commodities that felt the highest and immediate effects of the war on Ukraine in 2022 (Ruta, 2022; World Bank, 2023). Ethiopia has also been subject to multiple shocks in recent years (e.g., COVID-19 pandemic, droughts, and armed conflicts) leaving the country with little fiscal space to cushion the adverse spillover effects from the Russian invasion of Ukraine.

This study examines the economy-wide implications of changes in world prices for three commodities– wheat, fertilizers, and petroleum oil– highly significant for the Ethiopian food and energy systems. It applies a computable general equilibrium (CGE) model, which tracks the direct and induced economy-wide effects of the changes in world prices for the three major Ethiopian imports. Quantifying such effects and understanding their transmission mechanisms would provide lessons for possible policy responses in the advent of similar incidents with implications for global markets in the future.

The study explicitly represents the sectors and commodities linked to agrifood and energy systems and applied case-specific nesting of production and consumption functions to investigate the implications of world market prices changes to the food-energy nexus in Ethiopia and other low-income countries. The model combined production nesting features which are common in equilibrium model applications with detailed representation for energy (e.g., Feng & Zhang, 2018; Hutagalung et al., 2019) and agriculture (e.g., Hertel et al., 1996; Brunelle et al., 2015) sectors. The production nests allow for the imperfect substitution between different fuels (petroleum fuels, electricity, and biomass fuels) and, for growing crops, limited substitution between organic (animal manure) and inorganic (chemical) fertilizers, and then between composite fertilizer and land.

The study contributes to the literature on the transmission of shocks from global-to-domestic markets and their economy-wide impacts (e.g., Arndt et al., 2008; Dillon & Barrett, 2016; von Arnim et al., 2018), and the food-energy nexus (e.g., Mekonnen et al., 2017) in African countries.

The remainder of the paper is organized as follows. Section 2 presents the materials and methods of the study. Section 3 presents the results followed by Section 4 for the discussions. Section 5 concludes the paper.

2. MATERIALS AND METHODS

Given their detailed coverage of commodity and factor markets, and that of the circular flow of income, CGE models are widely applied for many trade, development, and fiscal policy issues of developing countries (Devarajan & Robinson, 2013). Single-country CGE modelling approach particularly helps to assess the direct and indirect effects of exogenous changes on different parts of the economy by comprehensively accounting for the country-specific interlinkages between production and consumption, and agrifood and energy sectors.

2.1. Model description

The Dynamic Equilibrium Model for Economic Development, Resources and Agriculture (DEMETRA) model is an extension of the STAGE_DEV model (McDonald et al., 2016). DEMETRA is a single-country recursive-dynamic small open-economy CGE model. The model allows for an advanced characterization of impacts of shocks at different levels: sectoral (output and production costs), household (income and consumption demand), factors (demand and income), and national (GDP, employment, and trade). DEMETRA incorporates behavioral equations that represent the economic relationships in developing countries: nested production and consumption functions and factor market segmentations (JRC, 2021; McDonald et al., 2016). The model and the underlying database have been applied in studies focusing on food security and agricultural policies in developing countries (Nechifor et al., 2021; Boulanger et al., 2022; Ntah et al., 2024). Further information and documentation about the model are available in JRC (2021).

2.2. Model calibration

The model assumes perfect competition in factor and commodity markets. Therefore, both the sellers and buyers in the factor and commodity markets take the prices determined by market supply and demand forces as given. Ethiopia is a small open-economy and thus its domestic price changes do not affect world market prices whereas world market price changes (of the country's exports and imports) are exogenous. In line with the Armington assumption (Armington, 1969), the imported and domestically produced varieties of commodities are imperfect substitutes. The elasticities used in production, commodity, and households' consumption nests are *ad hoc* values (summarized in Table A2 in the appendix) within the range found in the existing literature relevant for low-income countries and increase from agriculture to service sectors (e.g., Lofgren, 1994; Diao et al., 2012; Hertel & van der Mensbrugghe, 2019).

The production activities are disaggregated into sub processes captured by nested constant elasticity of substitution (CES) and Leontief production functions, which combine primary factors and intermediate inputs at different stages. The substitutions are driven by relative price changes. The decisions of production activities at different stages are driven by cost minimization goals constrained by market prices (of inputs and outputs) and production technology. The production technology nest of activities (Figure A1) is flexible and allows substitution possibilities among different factors and intermediate inputs at different levels. The top level is specified as Leontief aggregation of a composite intermediate input, and a composite valued-added-energy input, assuming a perfect complementarity between the two aggregates. The composite (aggregate) intermediate input is a Leontief aggregation of non-energy and non-fertilizer intermediate inputs. The composite value-added is a CES aggregation of a composite labor (of unskilled, semi-skilled, and skilled), a composite capital (of livestock, agricultural capital, non-agricultural capital), and a composite land (of irrigated or non-irrigated, and composite fertilizer) inputs. The composite energy input is a CES aggregate of energy commodities (electricity, fossil fuels, and bioenergy – fuelwood in hotels or biofuels in transport). Such nesting between energy and factor inputs resembles recent CGE applications (e.g., Feng & Zhang, 2018; Hutagalung et al., 2019). The value-added nest for crop-growing activities comprises a fertilizer nest which is a CES aggregation of animal manure (domestic) and inorganic (imported) fertilizers. This nest better represents the contexts in the country (Metaferia et al., 2011; AgSS, 2020) and allows for substitutability between them due to relative price changes which would not be allowed within the Leontief structure. In the recent five harvest seasons, about 45-50% and 11-13% of crop area cultivated by smallholder farmers in Ethiopia applies synthetic (inorganic) and natural (organic) fertilizers (AgSS, 2020). The composite fertilizer (of organic and inorganic types) is then treated as an imperfect substitute for cropland. The nesting structure for crop activities is also related to previous research on factor substitution in agriculture (e.g., Binswanger, 1974; Hertel, 1989; Ali & Parikh, 1992; Hertel et al., 1996; Dalton et al., 1997), and in agricultural land-use (e.g., Brunelle et al., 2015; Lungarska et al., 2023).

Households maximize their consumption utility subject to a nested Stone-Geary (or Linear Expenditure System – LES – demand) and CES functions (Figure A2), and to income constraints. In the Stone-Geary/LES utility function, at the top of the utility nest, household consumption demand consists of 'subsistence' demand and 'discretionary' demand. The commodities in the LES demand function are defined as 'broad' commodity groups, which are either aggregates of 'natural' commodities or individual 'natural' commodities that are deemed sufficiently distinctive as to justify the assumption that they are characterized by having a distinct level of 'subsistence' demand (JRC, 2021). The second level of the utility functions nest is defined with CES preferences. It consists of six commodity categories representing cereals (6 commodities), livestock (7 commodities including fish), energy (8 commodities in which the 2 are electricity from off-grid and grid sources), processed food and beverages (4 commodities), sweets (sugar and honey), and transport services (equines and modern transport services). Two of the energy commodities (crop residues and biogas), and one of the transport services (from equines) are consumed only by rural households. Additionally, animal manure, crop residues, and biofuel are by-products from livestock, crops, and sugar manufacturing.

Households' consumption expenditure is a residual of household income after deducting direct (income) taxes, savings, and their net transfers to other institutions (i.e., to the other household group, to enterprises, to the government, and to the rest of the world). Households' income sources include factors of production they own and supply, and net transfers from the rest of institutions. Households' consumption demand is therefore expected to be affected by changes in both households'

Table 1. Macro SAM of Ethiopia (2015/2016, billion birr).

	Activities	Commodities	Factors	Households	Enterprises	Government	Taxes	Investment	RestOfWorld	Total
Activities		2159.70								2159.70
Commodities	742.26	456.68		1096.46		148.84		591.58	123.21	3159.04
Factors	1425.11								7.83	1432.93
Households			1268.15		11.15	11.32			126.23	1416.84
Enterprises			158.60			5.52			0.28	164.40
Government				8.19	26.72		181.22		28.35	244.49
Taxes	-7.67	118.59		29.21	41.09					181.22
Investment				280.33	84.83	73.06			153.36	591.58
RestOfWorld		424.07	6.19	2.64	0.61	5.75				439.26
Total	2159.70	3159.04	1432.93	1416.84	164.40	244.49	181.22	591.58	439.26	

Source: Authors' elaboration.

income and commodity prices.

Factors can be mobile across activities (labor and land factors[1]) or activity-specific (capital and livestock factors). For the mobile factors, flexible average economy-wide wage rates equate their demand and supplies whereas flexible activity-specific wage distortion factors (proportions) equilibrate the markets for activity-specific factors. The supplies of primary factors of production are fixed at their base levels. Government and foreign savings are fixed at their base levels. The external (foreign sector) balance is maintained by a flexible exchange rate. All tax rates are fixed at the benchmark level.

2.3. Model database

The CGE model is calibrated to a modified version of the 2015/2016 social accounting matrix (SAM) for Ethiopia (Mengistu et al., 2019).[2] The adjusted SAM consists of 71 production activities (Table A1). The agriculture activities comprise 30 crop-growing activities, 7 livestock raising activities, and 4 other allied activities to agriculture. There are 8 industrial and 6 service activities. The remaining 16 activities are related to energy sectors.

The modified SAM comprises 51 commodities of which 28 are exportable. Synthetic (inorganic) fertilizers and petroleum oils are virtually all imported. There are 17 primary factor accounts representing different labor (3 by level of skill), land (rainfed and irrigated), capital (5 by primary use of the capital), and livestock (7 by species). There are four tax accounts representing domestic sales taxes, import tariffs and duties, direct (income) taxes, and subsidies to selected electricity producing activities (recorded in the SAM as negative taxes in Table 1). The SAM comprises five accounts representing two households (rural and urban), enterprises, government, and the rest of the world. The remainder of the SAM accounts represent trade and transport margin (or transaction costs), and disaggregated investment accounts.

Primary factors account for 66% of the production costs. Approximately 90% of the factor incomes goes to households. Imports account for about 14% of the supply of commodities. Consumption (77%) and savings (20%) are the main households' expenditure items whereas public services (61%) and savings (30%) are the main government expenditures. The inflows from the rest of the world include foreign saving (which is current account deficit for Ethiopia) (35%), remittances (29%) and export earnings (28%). Households' consumption (35%), intermediate inputs (23.5%), and investment demand (18.7%) are the main sources of demand for domestically supplied goods and services while export demand accounts for approximately 4%. Factor incomes (88.5%) followed by remittances (8.9%) are the main sources of households' income. Taxes are the main source of government revenue as they account for 74% of the total government income. About 65% of tax revenues are collected from commodities (on imports and on domestic sales) followed by income taxes from households and enterprises (30%). Production subsidies (applicable only to the power sector) account for - 4% of the total tax revenue. Ethiopian households and foreign sources contribute to 47% and 26% of the total national saving, with the remaining saving coming from enterprises and the government. Imports constitute about 97% of the total outflows from Ethiopia to the rest of the world.

The 2015/2016 SAM was updated using the recursive features of DEMETRA to the year 2022 using actual and

[1] Sensitivity analysis was performed with partially and entirely activity-specific croplands.

[2] Additional notes regarding adjustment of the SAM are given in the Appendix.

forecasted growth rates of GDP (IMF, 2022) and population (UN, 2022b). The forecasted real GDP growth rate for 2022 was 3.8% (IMF, 2022). We assume this GDP growth rate, which is lower than the country's five-year average of 8% growth rate (IMF, 2022; NBE, 2023), accounted mainly for the impacts of recent crises on Ethiopia but little for anticipated cascading effects from the Russia's invasion of Ukraine war impacts on world markets.

The calibration process and the adjusted SAM represent the contexts of the country and make the model suitable to address the study's research question. The production nest for crops along with the households' utility nest for energy commodities allow capturing the competition between agriculture and energy for animal manure (Mekonnen et al., 2017). The possibility of substitution between different fuel types (agricultural residues, fuelwood, petroleum products and electricity services) captures the "fuel stacking" behavior of Ethiopian households (Yalew, 2022).

2.4. World price change impact scenarios

The effects of global commodity supply, transport and logistics disruptions, the sanctions against Russia, the export bans adopted by some countries, and speculative market behaviors that ensued Russia's invasion of Ukraine have tremendously affected the prices for different world commodities in 2022 (World Bank, 2022). Although prices for some commodities showed a downward trend by the end of 2022 their level remained higher than in 2021 (World Bank, 2023).

Prices of many agrifood and energy commodities in Ethiopia increased in the past decade (ESS, 2023). Yet, the impacts of the recent domestic crises (e.g., armed conflicts, droughts) and international crises (e.g., COVID-19 pandemic and Russia's invasion of Ukraine) are conspicuous (NBE, 2023; EGTE, 2023). The annual average price indices for petroleum oil and wheat in the global and Ethiopian markets exhibit similar trends (Figure 1) substantiating the high inflation trends in Ethiopia in the past decade (ESS, 2023) as the local price changes grew faster compared to the world market prices. Likewise, domestic fertilizer prices increase might be larger than increases in world market fertilizer prices (Abay et al., 2024).

Global price changes would contribute to (or exacerbate) the domestic price changes which is why it is imperative to examine the implications of global commodity market shocks, such as those followed the war on Ukraine, for Ethiopia.

This study considers the impacts of world import price changes for three commodities (wheat, fertilizer, and petroleum products) which play substantial roles in the food and energy markets in Ethiopia and experienced more than 30% annual average real price changes in 2022 compared to 2021 (Table 2). The simulation scenarios are designed in a way to: (i) assess the potential losers from each commodity price change, (ii) identify the dominant impact channel, and (iii) assess the com-

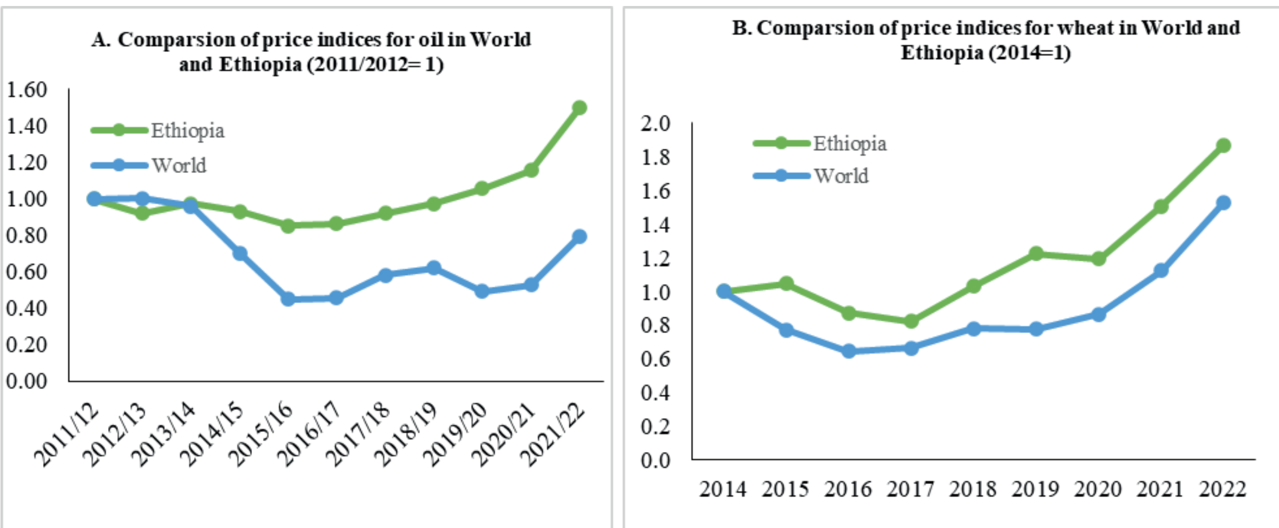

Figure 1. Comparison of local and world price indices for wheat and petroleum oil. Source: Authors' illustration based on data compiled from various reports by the National Bank of Ethiopia (retail gasoline price in Addis Ababa, Ethiopia), the Ethiopian Grain Trade Enterprise (wholesale wheat price in Ethiopia), and World Bank (2023) (crude oil and wheat prices in world markets). Trends for fertilizer prices were not presented here due to lack of publicly available local price data.

Table 2. Summary of the simulation scenarios.

Scenario	Description	Import price shocks
Wheat	World wheat import price changes	+ 34%
Fertilizer	World fertilizer import price changes	+ 54%
Petroleum	World petroleum oils import price changes	+ 50%
Combined	Combination of the above impact scenarios	

Source: Authors' calculations from World Bank (2023).
Note: The annual average real price changes, between 2022 and 2021, were calculated as of February 2023.

bined effects of the increase in the import prices of the three commodities.

Equations 1 to 4 capture the mechanisms to transmit the impacts of world import price changes to the Ethiopia's economy in DEMETRA:

$$PM_c = [PWM_c * (1 + TM_c)] * ER \tag{1}$$

$$QQ_c = \alpha_c * \ [\delta_c . QM_c{}^{-\rho_c} + \ (1 - \delta_c). QD_c{}^{-\rho_c}]^{\frac{1}{-\rho_c}}, \tag{2a}$$
$\forall c \in (cm \neq 0 \cap cd \neq 0)$

$$QQ_c = QM_c \ , \ \forall c \in cd = 0 \tag{2b}$$

$$\frac{QM_c}{QD_c} = \left[\frac{PD_c}{PM_c} * \frac{\delta_c}{(1-\delta_c)}\right]^{\frac{1}{(1+\rho_c)}}, \tag{3}$$
$\forall c \in (cm \neq 0 \cap cd \neq 0)$

The domestic price of competitive imports for commodity c (PM_c) is a product of the world price of imports (PWM_c, denominated in foreign currency, assumed to be exogenously determined and fixed by the world markets), the exchange rate (ER, domestic per foreign currency), and the import tariff rate (TM_c) (Equation 1). The equation applies for wheat, fertilizer, and petroleum fuels. Imported (QM_c) and domestic (QD_c) varieties are imperfect substitutes whose CES (or Armington) aggregation (QQ_c, the aggregate domestic supply of commodity c) is influenced by the share (δ), the elasticity of substitution (ρ), and the shift (α) parameters, for all commodities, such as wheat, which have both domestically produced (cd) and import (cm) varieties (Equation 2a). However, for some commodities such as fertilizers and petroleum oil their domestic supplies supply is composed of imports only (Equation 2b). The cost minimization behavior of domestic agents (i.e., deriving the first order conditions of Equation 2a), determines the optimal mix of supplies from domestic and foreign (import) producers depending on the relative price of domestic (PD_c) and import (PM_c) varieties of the same commodity (Equation 3).

For each cropping activity a, we endogenize land productivity to consider the yield improving role of chemical fertilizer application. Crop yields ($Y_{l,a}$) endogenously respond to the relative changes to the chemical fertilizer application, i.e., the application in the new scenario ($D^N_{f,a}$) relative to the application in the base scenario ($D^B_{f,a}$). The response factor (μ_f) consider the crop phenological responses to chemical fertilizer application, and thus translating into a change in crop yield per unit of cultivated land (Equation 4).

$$Y^N_{l,a} = Y^B_{l,a} * \left[\frac{D^N_{f,a}}{D^B_{f,a}}\right]^{\mu_f} \tag{4}$$

The value of response factors (was obtained from a relevant study (Sheahan et al., 2016) and can be interpreted as a 1% increase (decrease) in fertilizer application leads to a 0.21% increase (decrease) in crop yield. Although the yield responses to fertilizer use could vary by crop type (Hertel et al., 1996; Rashid et al., 2013), due to lack of information, we applied a uniform response rate for all crops, which we acknowledge as a limitation.

The three commodities considered are essential items in both production and final consumption sectors. They account for one-fifth of the total spending for merchandise imports in Ethiopia (NBE, 2023). Ethiopia is a net importer of wheat with imports accounting for a quarter of the wheat supply. According to the SAM, wheat accounts for 3.3% of total imports of goods and services and it is consumed as an intermediate input (26%) and as food by households (74%). The LES-CES utility functions nest employed in the model allows the possibility that households substitute wheat by other cereals such as teff, barley, maize, and sorghum depending on their relative price changes.

Ethiopia depends on imported chemical fertilizers and petroleum products. Fertilizer imports comprise approximately 2% of the total good and services imports in the SAM. Fertilizers are used as inputs in crop-growing activities and more than 50% of the supply is used in growing major cereal crops e.g. wheat, maize, teff, barley, and sorghum. In wheat and maize, chemical fertilizers account for up to 6.5% of the total production costs. Increasing chemical fertilizer prices are expected to reduce the use of chemical fertilizers by crop growing activities, and partly cropland productivity (Equation 4).

Petroleum fuels account for about 10% of imports of goods and services in the SAM. They are consumed as inputs in agriculture (0.4%), industry (28.1%), electricity (2.7%), transport (51.3%), and the rest of services (10.7%). Households' demand represents 6.8% of the demand for petroleum fuels while petroleum fuels account for only 0.4% and 0.5% of rural and urban households' consumption expenditure. The bigger proportion of petroleum fuel price change impact on households' welfare is expected through indirect effects (i.e., higher commodity prices due to increased production costs in most of the sectors as consequence of higher petroleum prices).

3. RESULTS

The subsections below present the impacts of world commodity price increases on different components of Ethiopian economy. All results are presented as percentage changes relative to the base scenario, which represents the counterfactual Ethiopian economy in 2022 without economic repercussions from Russia's invasion of Ukraine. One could consider the impact scenarios as "what if" scenarios in which the information on world import price changes (Table 2) were projected and communicated in advance as soon as the war on Ukraine began (say as early warnings). This would have helped Ethiopian producers and consumers plan and undertake anticipatory measures (e.g., factor allocations and adjustments in consumption demand) in response to the anticipated repercussions from the global market shocks but no significant investment and policy changes.

3.1. Impacts on the macroeconomy

The combined world price changes could reduce Ethiopia's real GDP (by 0.65%), imports (by 5.5%), private consumption (by 2.7%), and investment demand (by 1.3%) (Table 3). Likewise, the absorption, which measures the domestic expenditure on goods and services, falls by 2%. The effects are driven by the fertilizer and fuel price changes although wheat prices have a marked impact on the trade balance. Increasing wheat import price decreases wheat imports (and hence total imports) but increases domestic wheat production as well as its substitute cereals (to meet the supply gap) which would pull factors from other sectors including those contributing to exports such as coffee, oilseeds, and manufactured foods and beverages.

As production in some activities contract (and hence factor employment and income) direct tax and total government revenue decline by 4.1% and 0.54% in the combined impacts scenario.

Table 3. The impacts on the macroeconomy (% changes).

Variable	Import price change scenarios			
	Wheat	Fertilizer	Petroleum	Combined
GDP	-0.04	-0.32	-0.27	-0.65
Private consumption	-0.32	-0.74	-1.64	-2.70
Investment demand	0.13	-0.10	-1.34	-1.34
Absorption	-0.16	-0.46	-1.39	-2.01
Government consumption	-0.12	0.22	0.25	0.39
Imports	-0.87	-0.83	-3.81	-5.53
Exports	-1.21	-0.25	2.12	0.55

Source: DEMETRA simulations.

Table 4. The impacts on domestic production by activity groups (% changes).

Activities	Import price change scenarios			
	Wheat	Fertilizer	Petroleum	Combined
Crops	0.35	-1.48	1.7	0.52
Livestock	-0.17	-0.07	-0.14	-0.35
Primary sectors – grazing, fishing, forestry, mining	-0.19	0.27	-0.41	-0.35
Food and Beverages	-0.87	-0.13	0.42	-0.57
Textiles, clothes, leather, and wood processing	-0.07	0.31	-0.32	-0.04
Rest of manufacturing	-0.08	0.59	0.09	0.68
Utilities - electricity and water	-0.08	-0.06	-2.72	-2.87
Construction	0.08	-0.04	-1.06	-1.03
Services - Private	-0.15	0.08	-2.59	-2.69
Services - Public	-0.11	0.16	0.07	0.14

Source: DEMETRA simulations.

3.2. Impacts on production activities

The domestic production in different sectors respond differently to the aggregate and individual commodity price changes (Table 4). The sectors with the highest contraction of output in the combined impacts scenario are services, construction and utilities largely driven by the fuel price changes. Production in the rest of manufacturing, natural resources-based primary sectors, and public services slightly expand (under fertilizer price changes) and in crops and food and beverages (under fuel price changes). Petroleum price change results in a wider range of output impacts (Figure 2).

Disaggregated results show that the impacts are highly scattered across sectors (Figure 2). Rising wheat prices expand domestic wheat production by 2.5%.

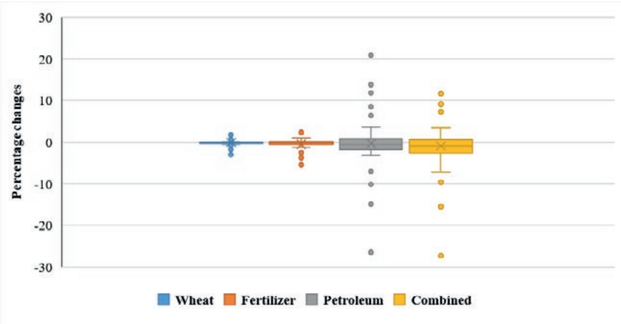

Figure 2. The impacts on domestic production activities (% changes). Source: DEMETRA simulations.

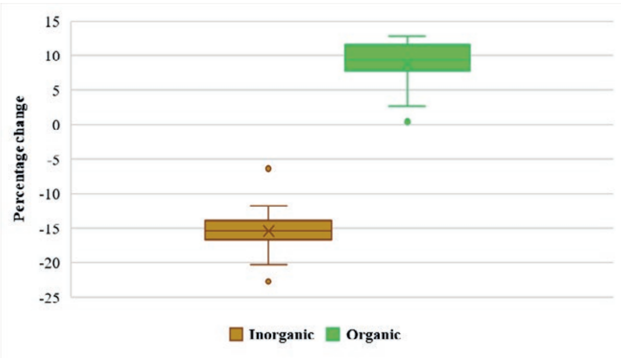

Figure 3. Fertilizer demand under inorganic fertilizer price increase scenario (% changes). Source: DEMETRA simulations.

Under petroleum price changes, domestic production expands in activities with substantial contribution to exports (oilseeds, coffee, vegetables, cotton, and tea) and electricity-powered transport services. The expansion of production in export-oriented agricultural activities derived from the depreciating exchange rates (due to higher import bills) making Ethiopian exports cheaper in the world markets and thus to balancing the increasing import costs. In contrast, rising fuel prices reduce the outputs from fuel-powered transport services, diesel-powered electricity (from grid and off-grid systems), and other private (commercial) services which includes hotels, financial intermediaries, and other business services. Consequently, exports from fuel-powered transport services and, slightly, electricity utilities decline.

Production in most cropping activities contracts following the rise in world chemical fertilizer prices (Table 4) with negligible size except for oilseeds, wheat, and maize which declined by 5.4%, 3.8%, and 3.2%. The marginal effects on the other crop growing activities are explained by the small shares of inorganic fertilizer inputs in the base scenario and from the substitution by manure (organic) for inorganic fertilizers (Figure 3). This, however, reduces manure available for household energy (Table 6).

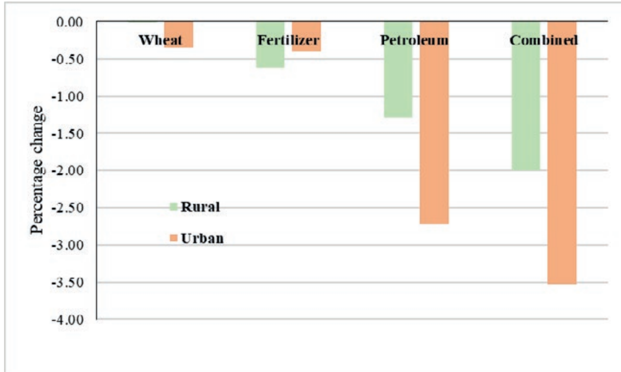

Figure 4. The impacts on households' consumption expenditure (% changes). Source: DEMETRA simulations.

3.3. *Impacts on households' consumption*

Rising import prices affect households' consumption demand directly (due to increased prices) and indirectly (declining household incomes as factor incomes fall due to contraction of production). In the combined impacts scenario, factor income decreases in thirteen of the seventeen factors. For instance, labor factor incomes decline by approximately 2% for unskilled to approximately 4% for semi-skilled and skilled labor categories whereas households' income from enterprises decline by about 10% (of which 7% is due to the petroleum price increases).

The decline in households' income and the resulting decrease in demands for commodities (due to higher prices) result in declining households' consumption by 2% for rural and 3.5% for urban households (Figure 4). The effects on the household groups vary across import price change scenarios. Urban households are worse off when it comes to wheat and fuel price changes whereas rural households are worse off under fertilizer price changes. The adverse effects on both household groups are mostly driven by petroleum price increases because petroleum products are inputs in almost all activities (and thus the rise in fuel prices increases in the costs of production and reduces factor demands and incomes) and as final demand product by households (and thus increasing price reduces quantity demanded).

3.4. *Implications for food security*

Of the four dimensions of food security, i.e., availability, accessibility, utilization, and stability (Peng and

Table 5. Implications for food security (% changes).

Scenario	Food Production Index	Food Price Index		Food Consumption	
		Rural	Urban	Rural	Urban
Wheat	0.10	0.80	0.34	0.14	-0.19
Fertilizer	-1.19	0.80	0.41	-0.41	-0.21
Petroleum	1.49	0.00	-0.08	-1.17	-2.39
Combined	0.35	1.48	0.60	-1.53	-2.84

Source: DEMETRA simulations.

Table 6. Impacts on household energy demand (% changes).

Fuels	Fertilizer		Petroleum	
	Rural	Urban	Rural	Urban
Residues	-1.39		0.65	
Wood	-0.12	0.02	-0.03	-0.76
Manure	-5.42	-3.20	-0.98	-1.33
Petroleum	-1.78	-0.98	-45.95	-31.38
Biogas	-0.81		0.16	
Ethanol	-1.26	-0.67	13.55	7.12
Electricity, off-grid	-0.41	-0.16	-9.06	-6.24
Electricity, grid	-0.66	-0.31	-5.16	-3.84

Source: DEMETRA simulations.

Berry, 2019); the rise in world import prices are expected to directly affect food *availability* (i.e., reduced wheat imports and reduced agricultural output due to expensive fertilizers and to some extent fuel prices), *accessibility* (i.e., increased transport costs and/or reduced transport services), and *stability* (i.e., the ability of the country's food system to withstand other natural and man-made shocks in the future due to reduced economic growth and government revenue).

Except for rural households under the wheat price change scenario, rural and urban households' food consumption decline (Table 5). Mirroring the impacts on crop production (Table 4), the index of food production, which includes crops, sugar, processed foods, and fish, declines (by 1.2%) only under the fertilizer price scenario (Table 5). The increase in food production index under petroleum price change is explained by increased agricultural exports, as discussed earlier.

The impacts on food production (Table 5) are negligible in most cases except under higher world prices for inorganic fertilizers due to Ethiopia's low dependence on food imports while many food staples (including teff and sorghum) are not traded internationally in large volumes (Diao et al., 2022). Yet, the index of food production increase includes overall crop production, most of which go to exports rather than to households in this scenario. That is why food consumption in both rural and urban households decreased despite the increased food production index (Table 5). The possibility of substitutions (e.g., wheat by other cereals, inorganic fertilizer by animal manure) allowed by the model contributed to relieve some of the price increase burdens on households' consumption.

3.5. Implications for household energy

The repercussions on households' energy consumption have implications for the food-energy nexus in Ethiopia (Mekonnen et al., 2017; Yalew, 2022). Agricultural wastes (e.g., crop residues, and animal dung) and products (e.g., biogas, ethanol) are important sources of household energy but using agricultural waste as fuel reduces organic fertilizer available for cropping activities.

The changes in demand for energy fuels are higher in rural households (Table 6) because they have a wider option of fuels, and hence their demand for a specific fuel is set to be relatively elastic compared to that in urban households. Petroleum prices affect households' energy prices directly (e.g., gas and kerosene) and indirectly (e.g., electricity from diesel generators). Indeed, as discussed in Section 2, the demand for petroleum in production activities is also significant. The decrease in petroleum fuel demand entails an increase in ethanol consumption in both household groups. Since ethanol is mostly produced from sugar molasses, in the long-term, this is an additional motive to expand sugar manufacturing capacities in the country. The combination of these mechanisms results in a differentiated price increase of the aggregate energy for households (by 1.5% for rural and by 3.5% for urban households). The combined share of electricity and ethanol in the total households' energy consumption is 5% while grid electricity accounts for about 18% of the urban households' energy consumption expenditure. As such, part of the decline in electricity demand is also associated with decreasing households' income in addition to its price change relative to other fuels. Rising inorganic fertilizer price increases the demand for animal manure as organic fertilizer (Figure 3) and hence reduces the amount of manure consumed as fuel by households. Demand for animal manure used as household energy declines by 5.4% and 3.2% in rural and urban households (Table 6). Increasing petroleum prices induces a slight increase in the use of biogas by rural households. This has positive implication for the domestic (household) biogas sector which converts cattle dung to fuel (biogas) and fertilizer (bio-slurry). As such, although the biogas sector in Ethiopia is yet at its niche phase (Kamp & Forn, 2016; Yalew, 2021), support for the biogas sector has the potential to help agrifood and energy sectors in the face of world petroleum price crises.

3.6. Senstivity analysis

Finally, we performed sensitivity analyses for the Armington (import) substitution elasticities (as the exogenous shocks analysed are related to import price changes) and two main assumptions pertaining to the crop sector (as the sector is important source of domestic food supply and exports). First, the overall results and conclusions remain less sensitive to increasing or decreasing the Armington import substitution elasticities by 30% (Table A3). An exception is that with higher elasticity of import substitutions, as import prices increase, the demand for imported goods become relatively elastic and decline further with which the aggregate exports decrease as exchange rates depreciates lesser compared to the case with low import elasticities. Second, the severity of the impacts partly depends on the crop phenological response factor to inorganic fertilizer use. For instance, if crop yields would be less sensitive to the amount of inorganic fertilizer applied, the combined impact on the real GDP drops to -0.39% (Table A4). Third, we deviated from our initial assumption regarding the flexibility of cropland allocations. We assumed cropland is partially mobile by fixing the land for 14 perennial crops (of the total 32 land-based activities). We then assumed all land is crop-specific (fixed to all activities), i.e., land cannot be reallocated in responses to shocks compared to the initial assumption such that farmers would easily and quickly switch between the crops they want to cultivate in response of actual and anticipated shocks. The sensitivity results (Table A4) show that adverse effects worsen when cropland is assumed to be immobile across activities. The impacts are notable on the export sector which decline by 0.91% compared to an increase by 0.55% when cropland is assumed to be freely allocable (or mobile) to growing different crops. The contraction of exports implies that there will be lesser resources to finance imports, and thus total imports decline by 6.2% compared to by 5.5% under the assumption of fully mobile cropland.

4. DISCUSSIONS

The Russian invasion of Ukraine, since February 2022, had profound implications for the global and African economies. The war caused massive supply chain disruptions and mounting trade costs globally (UNCTAD, 2022) producing price spikes for many globally traded commodities (World Bank, 2022). In Ethiopia, information from the past decade shows that local price changes for domestic commodities with competitive imports exhibit similar trends to that of world price changes. This implies that global price changes would contribute or exacerbate the price changes due to domestic market conditions. This necessitates to evaluate the implications of global commodity market shocks for Ethiopia.

This study showed that the global market repercussions due to the war on Ukraine are likely to have negatively affected the aggregate imports, households' consumption, and labor wage rates in Ethiopia. The effect on the real GDP is approximately -0.65% and is comparable to Diao et al. (2022). Nevertheless, the impacts are unevenly distributed among different sectors and households. Crop growing activities substitute animal manure (domestic) for inorganic (imported) fertilizers that eventually could dampen the adverse effects on crop production. This, however, would reduce manure available as cooking fuel which substantiates the relevance of the food-energy nexus in the country (Mekonnen et al., 2017; Yalew, 2022). The impacts on consumption are worse for urban households compared to rural ones except under fertilizer import price changes. The results of this study are comparable to previous studies showing the detrimental effects of world commodity market impacts on African economies (Arndt et al., 2008; Dillon & Barrett, 2016; von Arnim et al., 2018).

Three caveats apply to this analysis. First, the behavioral and crop phenology parameters used in the model (i.e. model elasticities) influence the simulation results. Despite the model and the adjusted SAM employed allow capturing several contexts of the Ethiopian economy, as in most CGE models, the results are still influenced by the neoclassical assumptions of perfect competition in the CGE model. Likewise, in line with the tradition in CGE model calibrations (Lofgren, 1994; Devarajan & Robinson, 2013), most of the production, international trade, and consumption are *ad hoc* values in the range of previous literature and economic theory. We therefore performed several sensitivity analyses for a selected set of parameters and assumption affecting import substitutions (Table A3) and crop activities (Table A4). The results from the sensitivity analysis regarding cropland mobility across activities are in accordance with the findings of previous research (e.g., Salazar-Espinoza et al., 2015; Martey et al., 2022) which showed farmers shift land use away from cash and permanent crops (and thus Ethiopian exports fall) and devote more to growing staple crops in response to adverse natural and man-made shocks. The sensitivity analysis also substantiates the important role of inorganic fertilizers to enhance cropland productivity (Rashid et al., 2013; Sheahan et al., 2016) and of crop agriculture in Ethiopia (Mengistu et al., 2019; NBE, 2023). Our findings that farmers substitute animal manure for inorganic fertilizers are similar to Abay et al. (2024). The study, citing survey data, indicated that the surge in inorganic fertilizer price in recent years might have encouraged Ethiopian farmers to shift to organic fertilizers. However, more research on the empirical estimates for the elasticities of substitution between organic and inorganic fertilizers, and between land and fertilizer for Ethiopia and other agrarian countries is highly needed.

Second, the study does not explicitly incorporate the impacts from interactions with domestic crises (e.g., armed conflicts, droughts) that have severely impacted Ethiopia in 2022. The armed conflicts in northern Ethiopia, between 2020-2022, might have pushed additional 3 million peoples deeper into poverty (Endale, 2023) while the droughts in the southern and southeastern parts of the country had affected an estimated population of 24 million in 2022 (ACAPS, 2023). We assumed that the impacts due to the domestic crises are accounted in the projected GDP growth rate (IMF, 2022) which is used to calibrate the baseline scenario. This could be a limitation as such compounding factors could influence the magnitude of the impacts from world market shocks (Headey & Fan, 2008; Abbott & Borot de Battisti, 2011; Meyimdjui & Combes, 2021). Thirdly, we assumed the Government of Ethiopia would not consider the possibility of adopting policy responses counteracting these global shocks. Government responses to global commodity market shocks such as social protection programs, export restrictions, price caps, subsidies, and tax reliefs (Abay et al., 2023) could have dampened the adverse impacts on production and consumption but mostly by transferring the burden to fiscal deficits (Headey & Fan, 2008; Ntah et al., 2024). Future research examining the interactions, and the combined effects of domestic and international market disruptions will be helpful.

5. CONCLUSIONS

This study assessed the consequences of the global commodity price changes in 2022, which followed from Russia's invasion of Ukraine, on Ethiopia. The results show that repercussions from global commodity market price increases adversely affect imports and households' consumption in Ethiopia. Rising petroleum prices increase households' demand for ethanol and biogas that can be considered as co-benefits to expanding sugar manufacturing and household biogas digesters. Rising fertilizer prices tighten the competition for the use of animal manure between cropping activities (as fertilizer) and households (as fuel). Policy measures to support the expansion of household (domestic) biogas digesters producing biogas (fuel) and bio-slurry (fertilizer) could be one mechanism to promote an optimal use of animal manure at the time of contemporaneous shocks to fertilizer and petroleum oil prices.

The study gleaned insights on how the different parts of the Ethiopian economy would respond to the world global commodity market shocks without explicitly incorporating other important internal natural and man-made crises that have battered the country in and around 2022. Further research on how these multiple impacts have interacted is highly needed to identify policy measures to build an economy resilient to simultaneous domestic and global market crises. The nature and size of these additional adverse conditions may become clearer in the medium-term.

DISCLAIMER

The views expressed in this paper are the sole responsibility of the authors and do not necessarily reflect the views of the European Commission.

REFERENCES

Abay, K.A., Assefa, T.W., Berhane, G., Abate, G.T., & Hebebrand, C. (2024). Grappling with compounding crises in domestic fertilizer markets in Africa: The case of Ethiopia. Research Post, IFPRI Blog. https://www.ifpri.org/blog/grappling-compounding-crises-domestic-fertilizer-markets-africa-case-ethiopia

Abay, K.A., Breisinger, C., Glauber, J., Kurdi, S., Laborde, D., & Siddig, K. (2023). The Russia-Ukraine war: Implications for global and regional food security and potential policy responses. *Global Food Security*, 36, 100675. https://doi.org/10.1016/j.gfs.2023.100675

Abbott, P., & Borot de Battisti, A. (2011). Recent Global Food Price Shocks: Causes, Consequences and Lessons for African Governments and Donors. *Journal of African Economies*, 20, 1: i12–i62. https://doi.org/10.1093/jae/ejr007

ACAPS. (2023). Impact of drought: Oromia and Somali regions. ACAPS, Geneva. https://www.acaps.org/en/

AgSS. (2016). Agricultural Sample Survey 2015/2016. Central Statistical Agency, Addis Ababa.

AgSS. (2020). Agricultural Sample Survey 2019/2020. Central Statistical Agency, Addis Ababa.

Ali, F., & Parikh, A. (1992). Relationships among labor, bullock and tractor inputs in Pakistan agriculture. *American Journal of Agricultural Economics*, 74, 2: 371-377. https://doi.org/10.2307/1242491

Armington, P. S. (1969). A Theory of Demand for Products Distinguished by Place of Production. *IMF Staff Papers*, 16, 1: 159–178.

Arndt, C., Benfica, R., Maximiano, N., Nucifora, A. M. D., & Thurlow, J. T. (2008). Higher fuel and food prices: Impacts and responses for Mozambique. *Agricultural Economics*, 39, 497–511. https://doi.org/10.1111/j.1574-0862.2008.00355.x

Badiane, O., Fofana, I., Sall, L. M., & Ceesay, B. (2022). Contagion and Exposure of African Countries to Global Wheat Trade Disruptions. Ukraine Crisis Brief Series, No. 01. AKADEMIYA2063, Kigali. www.akademiya2063.org

Binswanger, H.P. (1974). A Cost Function Approach to the Measurement of Elasticities of Factor Demand and Elasticities of Substitution. *American Journal of Agricultural Economics*, 56, 2: 377-386. https://doi.org/10.2307/1238771

Boulanger, P., Dudu, H., Ferrari, E., Mainar-Causapé, A. J., & Ramos, M. P. (2022). Effectiveness of fertilizer policy reforms to enhance food security in Kenya: A macro–micro simulation analysis. *Applied Economics*, 54, 8: 841–861. https://doi.org/10.1080/00036846.2020.1808180

Brunelle, T., Dumas, P., Souty, F., Dorin, B., & Nadaud, F. (2015). Evaluating the impact of rising fertilizer prices on crop yields. *Agricultural Economics*, 46: 653–666. https://doi.org/10.1111/agec.12161

Cai, Y., & Arora, V. (2015). Disaggregating electricity generation technologies in CGE models: A revised technology bundle approach with an application to the U.S. Clean Power Plan. *Applied Energy*, 154: 543-455. http://dx.doi.org/10.1016/j.apenergy.2015.05.041

Chepeliev, M. (2020). GTAP-Power 10a Database: a Technical Note. Research Memorandum No. 31. GTAP. Purdue University.

Dalton, T.J., Masters, W.A., & Foster, K.A. (1997). Production costs and input substitution in Zimbabwe's smallholder agriculture. *Agricultural Economics*, 17: 201-209. https://doi.org/10.1111/j.1574-0862.1997.tb00474.x

Devarajan, S., & Robinson, S. (2013). Contribution of Computable General Equilibrium Modeling to Policy Formulation in Developing Countries. *In Handbook of Computable General Equilibrium Modeling* (Vol. 1, pp. 277–301). https://doi.org/10.1016/B978-0-444-59568-3.00005-5

Diao, X., Dorosh, P. A., Kedir Jemal, M., Smart, J., Taffesse, A. S., & Thurlow, J. (2022). Ethiopia: Impacts of the Ukraine and global crises on poverty and food security. International Food Policy Research Institute (IFPRI), Washington, D.C. https://doi.org/10.2499/p15738coll2.135948

Diao, X., Thurlow, J., Benin, S., & Fan, S. (Eds.). (2012). Strategies and priorities for African agriculture: Economywide perspectives from country studies. International Food Policy Research Institute (IFPRI), Washington, D.C. https://doi.org/10.2499/9780896298125

Dillon, B. M., & Barrett, C. B. (2016). Global Oil Prices and Local Food Prices: Evidence from East Africa. *American Journal of Agricultural Economics*, 98, 1:154–171. https://doi.org/10.1093/ajae/aav040

EAPP. (2014). Regional Power System Master Plan: Volume II. Eastern Africa Power Pool (EAPP), Addis Ababa.

EGTE. (2023). Market Statistics. Ethiopian Grain Trade Enterprise (EGTE), Addis Ababa. https://www.egte-ethiopia.com/en/in-t-market/market-statistics.html

Endale, A. (2023). Conflict pushes 3m deeper into poverty. The Reporter. Addis Ababa. https://www.thereporterethiopia.com/34088/

ESC. (2019). Investment Opportunities in Ethiopian Sugar Industry. Ethiopian Sugar Corporation (ESC), Addis Ababa.

ESS. (2023). Country and Regional Level Consumer Price Indices. Information No. 49. Ethiopian Statistics Service (ESS), Addis Ababa.

Feng, S., & Zhang, K. (2018). Fuel-factor nesting structures in CGE models of China. *Energy Economics*, 75: 274-284. https://doi.org/10.1016/j.eneco.2018.08.030

Garicano, L., Rohner, D., & di Mauro, B. W. (Eds.). (2022). Global Economic Consequences of the War in Ukraine: Sanctions, Supply Chains and Sustainability. Centre for Economic Policy Research (CEPR), London.

GSE & JICA. (2015). The Project for Formulating Master Plan on Development of Geothermal Energy in Ethiopia: Executive Summary Final Report. Geological Survey of Ethiopia (GSE) and Japan International Cooperation Agency (JICA), Addis Ababa.

Guan, Y., Yan, J., Shan, Y., and et al. (2023). Burden of the global energy price crisis on households. *Nature Energy*, 8, 3: 304–316. https://doi.org/10.1038/s41560-023-01209-8

Hagos, F., Makombe, G., Namara, R. E., & Awulachew, S. B. (2009). Importance of irrigated agriculture to the Ethiopian economy: Capturing the direct net benefits of irrigation. Research Report 128, International

Water Management Institute (IWMI), Colombo, Sri Lanka.

Headey, D., & Fan, S. (2008). Anatomy of a crisis: The causes and consequences of surging food prices. *Agricultural Economics*, 39: 375–391. https://doi.org/10.1111/j.1574-0862.2008.00345.x

Hertel, T., & van der Mensbrugghe, D. (2019). Chapter 14: Behavioral Parameters: GTAP Resource No. 5950. Purdue University. https://www.gtap.agecon.purdue.edu/resources/res_display.asp?RecordID=5950

Hertel, T.W. (1989). Negotiating Reductions in Agricultural Support: Implications of Technology and Factor Mobility. *American Journal of Agricultural Economics*, 71, 3: 559-573. https://doi.org/10.2307/1242012

Hertel, T.W., Stiegert, K., & Vroomen, H. (1996). Nitrogen-land substitution in corn production: A reconciliation of aggregate and farm-level evidence. *American Journal of Agricultural Economics*, 78, l: 30–40. https://doi.org/10.2307/1243776

Hutagalung, A.M., Hartono, D., Arentsen, M.J., & Lovett, J.C. (2019). Economic implications of domestic natural gas allocation in Indonesia. *International Journal of Energy Sector Management*, 13,2:424-449. https://doi.org/10.1108/IJESM-05-2018-0003

IFPRI. (2014). Ethiopia Social Accounting Matrix (SAM), 2007. International Food Policy Research Institute (IFPRI). [dataset]. https://doi.org/10.7910/DVN/28527

Ihle, R., Bar-Nahum, Z., Nivievskyi, O., & Rubin, O. D. (2022). Russia's invasion of Ukraine increased the synchronisation of global commodity prices. *Australian Journal of Agricultural and Resource Economics*, 66, 4: 775–796. https://doi.org/10.1111/1467-8489.12496

IMF. (2022). War sets back the global recovery. International Monetary Fund (IMF), Washington, D.C. https://www.imf.org/en/Publications/WEO/Issues/2022/04/19/world-economic-outlook-april-2022

JRC. (2021). DEMETRA: Dynamic Equilibrium Model for Economic Development, Resources and Agriculture. European Commission Joint Research Center (JRC). https://datam.jrc.ec.europa.eu/datam/model/DEMETRA/index.html

Kamp, L.M., & Forn, E.B. (2016). Ethiopia's emerging domestic biogas sector: current status, bottlenecks and drivers. *Renewable and Sustainable Energy Reviews*, 60:475–488. https://doi.org/10.1016/j.rser.2016.01.068

Kruger, W., Stuurman, F., & Alao, O. (2019). Ethiopia Country Report. Report 5: Energy and Economic Growth Research Programme, Oxford.

LMSIS. (2017). Report on Large and Medium Scale Manufacturing and Electricity Industries Survey 2016/2017. Central Statistical Agency, Addis Ababa.

Lofgren, H. (1994). A Brief Survey of Elasticities for CGE Models. A Technical Report, Ford Foundation. https://doi.org/10.13140/RG.2.1.1295.6563

Lungarska, A., Brunelle, T., Chakir, R., Jayet, P., Prudhomme, R., De Cara, S., & Bureau, J. (2023). Halving mineral nitrogen use in European agriculture: Insights from multi-scale land-use models. *Applied Economic Perspectives and Policy*, 45, 3: 1529–1550. https://doi.org/10.1002/aepp.13391

Martey, E., Goldsmith, P., & Etwire, P.M. (2022). Farmers' response to COVID-19 disruptions: The case of cropland allocation decision. *Sustainable Futures*, 4, 100088. https://doi.org/10.1016/j.sftr.2022.100088

McDonald, S., Thierfelder, K., & Ariagie, E. (2016). A Static Applied General Equilibrium Model: Technical Documentation: STAGE_DEV Version 2. CGEMOD. https://cgemod.org.uk/

Mekonnen, D., Bryan, E., Alemu, T., & Ringler, C. (2017). Food versus fuel: Examining tradeoffs in the allocation of biomass energy sources to domestic and productive uses in Ethiopia. *Agricultural Economics*, 48, 4: 425–435. https://doi.org/10.1111/agec.12344

Mengistu, A. T., Woldeyes, F. B., Dessie, E., Ayalew, Z., Mainar Causapé, A. J., & Ferrari, E. (2019). Ethiopia social accounting matrix 2015/16. Publications Office of the European Union, Luxemburg. https://data.europa.eu/doi/10.2760/974668

Metaferia, F., Cherenet, T., Gelan, A., Abnet, F., Tesfay, A., Ali, J.A., & Gulilat, W. (2011). A review to improve estimation of livestock contribution to the national GDP. Ministry of Finance and Economic Development (MoFED), Addis Ababa.

Meyimdjui, C., & Combes, J.-L. (2021). Food Price Shocks and Household Consumption in Developing Countries: The Role of Fiscal Policy. IMF Working Paper No. 2021/012. International Monetary Fund (IMF), Washington, D.C.

MoFECC. (2017). Ethiopia Forest Sector Review. Ministry of Environment, Forest, and Climate Change (MoFECC), Addis Ababa.

MoFED. (2012). Ethiopian National Accounts: Concepts, Sources and Methods. Ministry of Finance and Economic Development (MoFED, Addis Ababa.

MoWIE. (2013). Updated Rapid Assessment and Gap Analysis on Sustainable Energy for All (SE4All). Ministry of Water, Irrigation, and Energy (MoWIE), Addis Ababa.

MoWIE. (2019). Energy Balance 2017/2018. Ministry of Water, Irrigation, and Electricity (MoWIE), Addis Ababa.

NBE. (2020). Annual Economic Report 2018/2019. National Bank of Ethiopia (NBE), Addis Ababa.

NBE. (2023). Annual Economic Report: 2021/2022. National Bank of Ethiopia (NBE), Addis Ababa.

NCDS. (2017). National Cotton Development Strategy (2018-2032) and Road Map. SOFRECO.

Nechifor, V., Ramos, M. P., Ferrari, E., Laichena, J., Kihiu, E., Omanyo, D., Musamali, R., & Kiriga, B. (2021). Food security and welfare changes under COVID-19 in Sub-Saharan Africa: Impacts and responses in Kenya. *Global Food Security*, 28, 100514. https://doi.org/10.1016/j.gfs.2021.100514

NEP. (2019). National Electrification Program 2.0: Integrated Planning for Universal Access. Ministry of Water, Irrigation, and Electricity (MoWIE), Addis Ababa.

Ntah, M.N., Nechifor, V., Ferrari, E., Nandelenga, M.W., & Yalew, A.W. (2024). The impacts of Russia's invasion of Ukraine on the Kenyan economy: Evidence from an economy-wide model. *African Development Review*, 1–14. https://doi.org/10.1111/1467-8268.12728

Osendarp, S., Verburg, G., Bhutta, Z., and et al. (2022). Act now before Ukraine war plunges millions into malnutrition. *Nature*, 604: 620–624. https://doi.org/10.1038/d41586-022-01076-5

Pappis, I., Sahlberg, A., Walle, T., Broad, O., Eludoyin, E., Howells, M., & Usher, W. (2021). Influence of Electrification Pathways in the Electricity Sector of Ethiopia – Policy Implications Linking Spatial Electrification Analysis and Medium to Long-Term Energy Planning. *Energies*, 14, 4: 1209. https://doi.org/10.3390/en14041209

Peng, W., & Berry, E. M. (2019). The Concept of Food Security. In *Encyclopedia of Food Security and Sustainability* (pp. 1–7). https://doi.org/10.1016/B978-0-08-100596-5.22314-7

Peters, J.C. (2016). The GTAP-Power Data Base: Disaggregating the Electricity Sector in the GTAP Data Base. *Journal of Global Economic Analysis*, 1,1: 209–250. https://doi.org/10.21642/JGEA.010104AF

Rashid, S., Tefera, N., Minot, N., & Ayele, G. (2013). Can modern input use be promoted without subsidies? An analysis of fertilizer in Ethiopia. *Agricultural Economics*, 44, 6:595–611. https://doi.org/10.1111/agec.12076

Ruta, M. (Ed.). (2022). The Impact of the War in Ukraine on Global Trade and Investment. World Bank, Washington, D.C. http://hdl.handle.net/10986/37359

Salazar-Espinoza, C., Jones, S., & Tarp, F. (2015). Weather shocks and cropland decisions in rural Mozambique. *Food Policy*, 53: 9–21. https://doi.org/10.1016/j.foodpol.2015.03.003

Sheahan, M., Ariga, J., & Jayne, T. S. (2016). Modeling the Effects of Input Market Reforms on Fertiliser Demand and Maize Production: A Case Study from Kenya. *Journal of Agricultural Economics*, 67, 2: 420–447. https://doi.org/10.1111/1477-9552.12150

Sue Wing, I. (2008). The synthesis of bottom-up and top-down approaches to climate policy modeling: electric power technology detail in a social accounting framework. *Energy Economics*, 30, 2: 547–573. https://doi.org/10.1016/j.eneco.2006.06.004

Tesfaye, G. (2020). Clean cooking with ethanol. Policy Brief. www.projectgaia.com. Accessed on May 03, 2021.

Tilahun, H., Telku, E., Michael, M., Fitsum, H., & Awulachew, S.B. (2011). Comparative Performance of Irrigated and Rainfed Agriculture in Ethiopia. *World Applied Sciences Journal*, 14, 2: 235–44.

Trimble, C., Kojima, M., Arroyo, I., & Mohammadzadeh, F. (2016). Financial Viability of Electricity Sectors in Sub-Saharan Africa: Quasi-Fiscal Deficits and Hidden Costs. Policy Research Working Paper 7788. World Bank, Washington, DC.

UN. (2022a). Global Impact of war in Ukraine on food, energy and finance systems. Brief No. 01. United Nations, New York. https://unsdg.un.org/resources/global-impact-war-ukraine-food-energy-and-finance-systems-brief-no1

UN. (2022b). World Population Prospects 2022. United Nations, New York. https://population.un.org/wpp/

UNCTAD. (2022). The Impact on Trade and Development of the War in Ukraine. United Nations Conference on Trade and Development (UNCTAD), Geneva. https://unctad.org/system/files/official-document/osginf2022d1_en.pdf

von Arnim, R., Tröster, B., Staritz, C., & Raza, W. (2018). Commodity price shocks and the distribution of income in commodity-dependent least-developed countries. *Journal of Policy Modeling*, 40, 2: 434–451. https://doi.org/10.1016/j.jpolmod.2018.02.008

World Bank. (2022). Commodity Markets Outlook: The Impact of the War in Ukraine on Commodity Markets, April 2022. World Bank, Washington, D.C. https://hdl.handle.net/10986/37223

World Bank. (2023). World Bank Commodity Price Data (The Pink Sheet)– February 2023. World Bank, Washington, D.C.

Yalew, A.W. (2021). Economic contributions and synergies of biogas with the SDGs in Ethiopia. *Energy Nexus*, 3, 100017. https://doi.org/10.1016/j.nexus.2021.100017

Yalew, A.W. (2022). The Ethiopian energy sector and its implications for the SDGs and modeling. *Renewable and Sustainable Energy Transition*, 2, 100018. https://doi.org/10.1016/j.rset.2022.100018

APPENDIX

1. Notes on SAM adjustment

This study used a modified version of the 2015/2016 SAM for Ethiopia (Mengistu et al., 2019). Important adjustments were made particularly pertaining to the agriculture, forestry, electricity, and transport sectors. For 14 crop growing activities, irrigated farming was separated from rainfed farming using information from agricultural surveys (AgSS, 2016) and other research reports (NCDS, 2017; Tilahun et al., 2011; Hagos et al., 2009). The livestock sector was further disaggregated to explicitly account for 7 types of activities (cattle, sheep, goats, camels, equines, poultry, and beekeeping) using information from agricultural survey (AgSS, 2016) and national income accounts (MoFED, 2012). Animal feed

Table A1. List of activities in the SAM and their group for reporting results.

Group	Activity	Group	Activity
Crops	Growing *rainfed* teff	*Primary sectors*	Managed natural grass fodder
Crops	Growing *irrigated* teff	*Primary sectors*	Fish
Crops	Growing *rainfed* barley	*Primary sectors*	Forestry
Crops	Growing *irrigated* barley	*Primary sectors*	Mining and quarrying
Crops	Growing *rainfed* wheat	*Food & Beverages*	Processed and manufactured foods
Crops	Growing *irrigated* wheat	*Food & Beverages*	Sugar
Crops	Growing *rainfed* maize	*Food & Beverages*	Beverages and tobacco
Crops	Growing *irrigated* maize	*Textiles, clothes…*	Textile, leather, clothes, and wood processing
Crops	Growing *rainfed* sorghum	*Rest of manufacturing*	Rest of manufacturing
Crops	Growing *irrigated* sorghum	*Construction*	Construction
Crops	Growing *rainfed* pulses	*Utilities*	Water supply
Crops	Growing *irrigated* pulses	*Utilities*	Off-grid electricity, diesel
Crops	Growing *rainfed* oilseeds	*Utilities*	Off-grid electricity, solar
Crops	Growing *irrigated* oilseeds	*Utilities*	Grid electricity, hydro, Abbay basin
Crops	Growing *rainfed* vegetables	*Utilities*	Grid electricity, hydro, Omo basin
Crops	Growing *irrigated* vegetables	*Utilities*	Grid electricity, hydro, Awash basin
Crops	Growing *rainfed* fruits	*Utilities*	Grid electricity, hydro, Tekeze basin
Crops	Growing *irrigated* fruits	*Utilities*	Grid electricity, hydro, Wabi-Shebele basin
Crops	Growing coffee	*Utilities*	Grid electricity, hydro, Rest of basins
Crops	Growing enset	*Utilities*	Grid electricity, wind
Crops	Growing *rainfed* sugarcane	*Utilities*	Grid electricity, geothermal
Crops	Growing *irrigated* sugarcane	*Utilities*	Grid electricity, solar
Crops	Growing *rainfed* chat	*Utilities*	Grid electricity, municipal waste
Crops	Growing *irrigated* chat	*Utilities*	Grid electricity, diesel
Crops	Growing tea	*Utilities*	Grid electricity, transmission & distribution
Crops	Growing *rainfed* cotton	*Private Services*	Transport services, electricity-based
Crops	Growing *irrigated* cotton	*Private Services*	Transport services, fuel-based
Crops	Growing *rainfed* crops nec	*Private Services*	Rest of private commercial services
Crops	Growing *irrigated* crops nec.	*Public Services*	Public administration
Crops	Forage & bioenergy crops	*Public Services*	Education services
Crops	Cut flower	*Public Services*	Health services
Livestock	Cattle	*Public Services*	Health services
Livestock	Sheep		
Livestock	Goats		
Livestock	Camel		
Livestock	Poultry		
Livestock	Beekeeping		
Livestock	Equines		
Livestock	Domestic biogas		

sources include grass fodder, crop residues, animal forages, and proceed animal feed (AgSS, 2016). Forest products were disaggregated into three distinct products – wood fuel, industrial wood, and non-timber forest products (NTFPs) using product shares from the national income (MoFED, 2012) and forest sector accounts (MoFECC, 2017). Electricity production is disaggregated into off-grid and grid connections (MoWIE, 2013), and then by technology using information on installed capacities information (LMSIS, 2017; NBE, 2020; Pappis et al., 2021; GSE & JICA, 2015; EAPP, 2014) in line with the recent discussion regarding the power sector in CGE models (e.g., Chepeliev, 2020; Peters et al., 2016; Cai & Arora, 2015; Sue Wing, 2008). Electricity output also accounts for electricity from bagasse as byproduct from sugar manufacturing (ESC, 2019; Kruger et al., 2019). Further adjustment was made to account for the implicit subsidies to the state-owned electricity utility enterprise (Trimble et al., 2016) and export to neighboring countries (NBE, 2020). Electricity-based transport services (of Ethio-Djibouti Railway and Addis Ababa Urban Light Rail services) are distinguished from fuel-based (road and air transport) services. To better account for the interlinkages between agriculture and energy sectors, the adjusted SAM also contains biogas (activity and commodity) (Yalew, 2021) and biofuel (mainly as a byproduct from sugar molasses in sugar manufacturing (ESC, 2019; Tesfaye, 2020). Finally, compared to the initial SAM (Mengistu et al., 2019), the adjusted SAM contains highly aggregated manufacturing (as rest of manufacturing) and private services (as rest of commercial services). For some of the adjustments, when correspondence allows, cross-checks were made with the supply and use tables of the 2005/2006 SAM for Ethiopia (IFPRI, 2014).

2. Model calibration

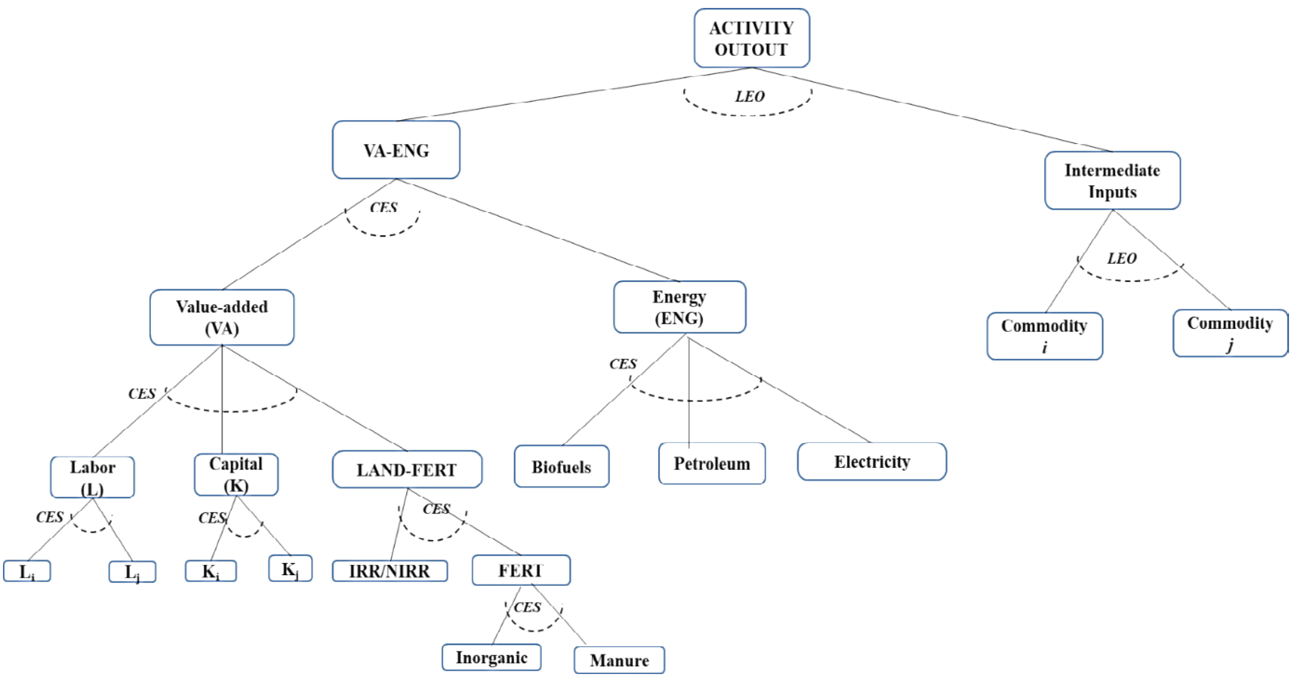

Figure A1. Production technology nest structure (author's elaboration).

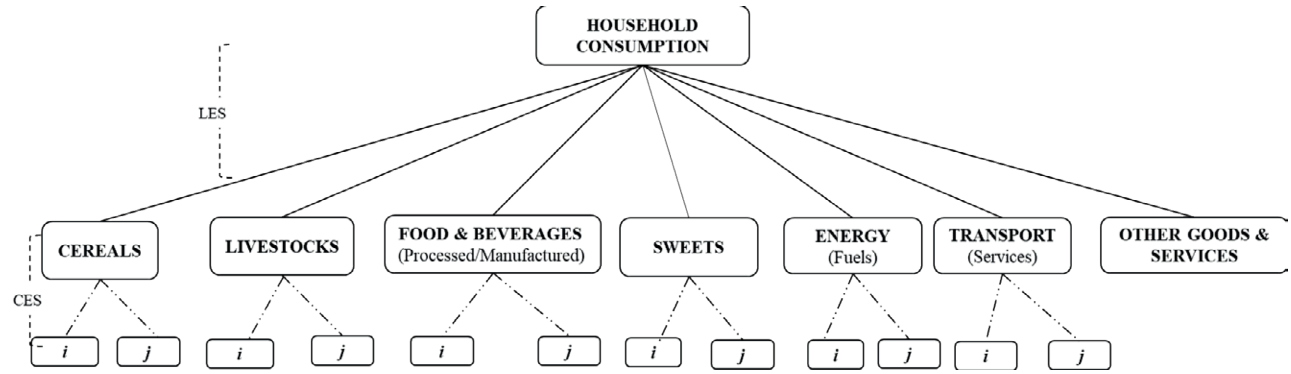

Figure A2. Households' utility nest (authors' elaboration).

Table A2. Range of production, trade, and consumption elasticities.

Type	Nest	Description	Range
Production	L	Elasticities of substitutions among different labor categories (e.g., skilled, semi-skilled, unskilled workers).	0.30–1.50
	K	Elasticities of substitutions among different capital categories (e.g., animal draught power, agricultural machinery, and non-agricultural capital).	0.20–1.50
	FERT	Elasticities of substitutions between organic and inorganic fertilizers.	0.70
	LAND-FERT	Elasticities of substitution between composite fertilizer and land factor.	0.30
	ENG	Elasticities of substitution between energy commodities for intermediate consumption (e.g., wood fuel, biofuel, petroleum oil, electricity).	0.30
	VA	Elasticities of substitutions among composite primary factors (e.g., labor, land, capital)	0.30–1.50
	VA-ENG	Elasticities of substitutions between composite energy and value-added.	0.30
	Intermediate	Elasticities of substitution among different intermediate inputs other than fertilizers and petroleum fuels.	0.00
	Top level	Elasticities of substitution between composite VA-ENG and intermediate inputs at the top of the nest.	0.00
Trade	Imports	Elasticities of substitution between import and domestic varieties of a commodity	0.80–3.00
	Exports	Elasticities of transformation between exports and domestic varieties of a commodity	0.80-3.00
Consumption	Households	Elasticity of substitution among consumption goods (only for those under CES nests)	0.75–2.50
	Households	Income elasticity of consumption demand	0.50–1.20
	Households	Frisch parameter	-1.50

3. Sensitivity analysis

Table A3. Sensitivity of simulation results to Armington (import) substitution elasticities.

Level	Variable	Armington elasticities [Table A2-30%]				Armington elasticities [Table A2]				Armington elasticities [Table A2 +30%]			
		WHT	FRT	PTR	CMB	WHT	FRT	PTR	CMB	WHT	FRT	PTR	CMB
Macroeconomic Indicators	GDP	-0.04	-0.33	-0.28	-0.66	-0.04	-0.32	-0.27	-0.65	-0.05	-0.32	-0.27	-0.65
	Private consumption	-0.33	-0.74	-1.63	-2.69	-0.32	-0.74	-1.64	-2.70	-0.31	-0.74	-1.65	-2.70
	Investment demand	0.07	-0.13	-1.36	-1.44	0.13	-0.10	-1.34	-1.34	0.18	-0.09	-1.33	-1.26
	Absorption	-0.18	-0.46	-1.39	-2.03	-0.16	-0.46	-1.39	-2.01	-0.14	-0.46	-1.40	-2.00
	Government consumption	-0.06	0.27	0.31	0.56	-0.12	0.22	0.25	0.39	-0.16	0.18	0.21	0.26
	Imports	-0.82	-0.81	-3.61	-5.24	-0.87	-0.83	-3.81	-5.53	-0.90	-0.85	-3.98	-5.76
	Exports	-0.77	-0.19	2.56	1.49	-1.21	-0.25	2.12	0.55	-1.55	-0.29	1.73	-0.23
Activity Outputs	Crops	0.25	-1.45	1.67	0.45	0.35	-1.48	1.70	0.52	0.43	-1.51	1.73	0.59
	Livestock	-0.15	-0.06	-0.17	-0.36	-0.17	-0.07	-0.14	-0.35	-0.18	-0.07	-0.12	-0.34
	Primary sectors – grazing, fishing, forestry, mining	-0.14	0.27	-0.46	-0.35	-0.19	0.27	-0.41	-0.35	-0.23	0.27	-0.37	-0.34
	Food and Beverages	-0.80	-0.16	0.24	-0.74	-0.87	-0.13	0.42	-0.57	-0.93	-0.12	0.58	-0.43
	Textiles, clothes, leather, and wood processing	-0.02	0.25	-0.61	-0.36	-0.07	0.31	-0.32	-0.04	-0.12	0.34	-0.09	0.18
	Rest of manufacturing	-0.01	0.52	-0.22	0.35	-0.08	0.59	0.09	0.68	-0.15	0.62	0.32	0.88
	Utilities - electricity and water	-0.06	-0.07	-2.72	-2.87	-0.08	-0.06	-2.72	-2.87	-0.09	-0.05	-2.73	-2.88
	Construction	0.04	-0.07	-1.14	-1.18	0.08	-0.04	-1.06	-1.03	0.11	-0.01	-0.99	-0.91
	Services - Private	-0.11	0.05	-2.46	-2.57	-0.15	0.08	-2.59	-2.69	-0.18	0.10	-2.71	-2.82
	Services - Public	-0.06	0.20	0.11	0.28	-0.11	0.16	0.07	0.14	-0.14	0.13	0.03	0.04
Consumption	Rural	-0.01	-0.59	-1.25	-1.93	-0.01	-0.62	-1.29	-2.00	0.00	-0.64	-1.31	-2.04
	Urban	-0.26	-0.38	-2.70	-3.39	-0.35	-0.41	-2.72	-3.52	-0.42	-0.42	-2.74	-3.62

Source: DEMETRA simulations.
Notes: WHT – Wheat, FRT – Fertilizer, PTR – Petroleum, and CMB – Combined price scenarios.

Table A4. Sensitivity of simulation results to assumptions affecting crop activities.

Level	Variable	Crop phenology is less sensitive to the level of chemical fertilizer				Land partially mobile across activities				Land immobile across activities			
		WHT	FRT	PTR	CMB	WHT	FRT	PTR	CMB	WHT	FRT	PTR	CMB
Macroeconomic Indicators	GDP	-0.05	-0.05	-0.28	-0.39	-0.04	-0.32	-0.29	-0.67	-0.04	-0.32	-0.33	-0.71
	Private consumption	-0.33	-0.33	-1.64	-2.28	-0.32	-0.75	-1.64	-2.70	-0.31	-0.75	-1.67	-2.72
	Investment demand	0.15	-0.12	-1.43	-1.41	0.14	-0.09	-1.44	-1.42	0.18	-0.07	-1.67	-1.58
	Absorption	-0.16	-0.23	-1.41	-1.79	-0.15	-0.46	-1.42	-2.03	-0.14	-0.46	-1.48	-2.08
	Government consumption	-0.13	0.10	0.36	0.34	-0.12	0.20	0.34	0.46	-0.17	0.18	0.67	0.70
	Imports	-0.83	-0.53	-4.06	-5.38	-0.83	-0.82	-4.06	-5.72	-0.68	-0.74	-4.77	-6.15
	Exports	-1.10	0.56	1.54	1.03	-1.10	-0.20	1.54	0.14	-0.74	0.03	-0.18	-0.91
Activity Outputs	Crops	0.35	-0.41	1.61	1.54	0.33	-1.40	1.55	0.44	0.40	-1.36	1.19	0.19
	Livestock	-0.19	0.01	-0.04	-0.22	-0.12	-0.26	0.21	-0.15	-0.12	-0.25	0.34	-0.03
	Primary sectors – grazing, fishing, forestry, mining	-0.19	0.13	-0.41	-0.46	-0.12	0.14	-0.38	-0.37	-0.14	0.12	-0.31	-0.33
	Food and Beverages	-0.88	-0.08	0.48	-0.48	-0.87	-0.13	0.46	-0.53	-0.92	-0.07	0.61	-0.36
	Textiles, clothes, leather, and wood processing	-0.08	0.13	-0.19	-0.14	-0.07	0.29	-0.22	0.03	-0.13	0.26	0.16	0.31
	Rest of manufacturing	-0.11	0.26	0.29	0.47	-0.10	0.57	0.26	0.82	-0.20	0.52	0.89	1.27
	Utilities - electricity and water	-0.08	-0.05	-2.72	-2.86	-0.07	-0.06	-2.74	-2.88	-0.09	-0.06	-2.72	-2.88
	Construction	0.09	-0.08	-1.11	-1.10	0.09	-0.03	-1.12	-1.08	0.11	-0.02	-1.24	-1.18
	Services - Private	-0.16	0.02	-2.56	-2.71	-0.15	0.07	-2.59	-2.69	-0.19	0.05	-2.46	-2.61
	Services - Public	-0.12	0.07	0.15	0.11	-0.11	0.14	0.14	0.20	-0.15	0.12	0.41	0.40
Consumption	Rural	0.01	-0.28	-1.44	-1.75	0.02	-0.64	-1.41	-2.12	0.09	-0.60	-1.93	-2.48
	Urban	-0.36	-0.08	-2.74	-3.19	-0.34	-0.44	-2.72	-3.53	-0.34	-0.42	-2.79	-3.57

Source: DEMETRA simulations.
Notes: WHT – Wheat, FRT – Fertilizer, PTR – Petroleum, and CMB – Combined price scenarios. Under 'land partially mobile' sensitivity test, cropland for selected crops (i.e., fruits, coffee, tea, sugarcane, enset, chat, cotton, forage and bioenergy crops, grass fodder, and cut flower) was assumed to be activity-specific and hence cannot be reallocated in response to the anticipated impacts.