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Transport Frictions and the Pass-Through of Global Price Shocks in a Spatial Model of Low-Income Countries

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ABSTRACT: We develop a spatial dynamic general equilibrium model of a small open agricultural economy to study the impact of global food, fuel and fertilizer price shocks on consumption patterns of heterogeneous households located in different regions, under alternative fiscal responses, including direct price subsidies and household transfers. We show strong spatial heterogeneity in response to shocks, with associated implications for welfare. In particular, while urban households' consumption baskets are more exposed to the direct effects of global food price shocks, remote rural households' production and consumption are more exposed to supply-side dislocations associated with shocks to fuel and fertilizer prices.

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WORKING PAPERS

Transport frictions and the pass-through of global price shocks in a spatial model of low-income countries

Prepared by Lisa Martin, Christopher Adam, and Douglas Gollin[1]

1 Introduction

Recent years have seen increased volatility in world prices for food, energy and fertilizer. Most recently, the decompression of the post-pandemic global economy, combined with Russia's invasion of Ukraine, saw the real prices of energy and fertilizers almost double between 2020 and 2022, while the composite global tradable food price index rose by around 30 percent over the same period before returning to pre-pandemic levels (Figure 1).

Low-income countries (LICs) tend to be particularly strongly affected by such shocks. But the transmission of global price shocks through the domestic economy is highly dependent on the internal structures of individual economies – with corresponding implications for the distributional effects of price shocks and the effectiveness of policy responses. In particular, the transmission of external price shocks to domestic firms and households is mediated by spatial and sectoral frictions, reflecting the underlying spatial dispersion of populations and the geography of production. The magnitude of these frictions depends on internal transport costs, which are in turn determined by the extent of transport infrastructure and the degree of competition in transport services. Together, these frictions induce strong spatial differences in the level and composition of production, consumption, and trade: different locations and different components of the economy thus experience heterogeneous impacts from global price shocks. As a consequence, policy-making must be attuned both to the spatial heterogeneity of shocks and to the distributional consequences of policies aimed at shielding spatially distributed vulnerable populations.

The primary purpose of this paper is to develop a dynamic general equilibrium model that allows us to study the spatially differentiated impacts of global price shocks on a low-income small open agricultural economy representative of those of sub-Saharan Africa, and to use this framework to consider alternative fiscal policy responses to these sorts of shock. The model allows us to identify key pass-through mechanisms from external shocks to domestic production, consumption, household income and welfare, across locations and households and to examine how these effects are modified under alternative fiscal mitigation measures and financing strategies.[1] Our framework embeds a rich multi-sector spatial structure within the workhorse DIG model framework widely used across the International Monetary Fund (see, for example Gurara et al. (2019)).

To illustrate its properties we calibrate the model to data from Tanzania and then use it to examine the impact of the the 2021/22 global price shocks under alternative stylized fiscal policy responses.[2] Specifically, we compare a policy response based on the use of targeted subsidies on food, fuel and fertilizer with an alternative policy of issuing cash transfers to households. Both sets of policies are analyzed under alternative assumptions concerning the

[1] While our focus in this paper is on external price shocks, this framework can be used to examine other sources of price and productivity volatility. Notably, recent related work by Baptista et al. (2022) examines the spatially differentiated effects of climate-induced shocks to agricultural productivity.

[2] As described below, the calibration is based on data from the Tanzania Social Accounting Matrix (SAM), World Bank Living Standards Measurement Survey (LSMS) data and IMF country reports.

balance of financing between external concessional financing, domestic tax financing, and domestic debt.

The model structure is, however, quite general and can be readily adapted to other country settings but particularly for those characterized by significant spatial dispersion of production and consumption.

Using the Tanzania application, we first show how price shocks propagate through the domestic economy. In part, propagation is driven by direct demand-side impacts on consumer prices with particularly strong impacts on the consumption of urban households whose propensity to consume imports is high. But an important additional channel is through the supply side of the economy, where increased costs of imported intermediate goods - fuel and fertilizer – raise both the costs of production in agriculture and, in the case of fuel, increase transport costs, adversely affecting the production of internally and externally tradable output, including cash crop exports.

One key insight from this exercise is the tension between policy measures that directly support rural welfare in the face of price increases and those that neutralize relative price effects and thereby minimize the disruption and dislocation of production.

There is a vast literature on the impact of price shocks. Much of this focuses on aggregate country-level analyses, assessing vulnerability to shocks based on national trade statistics, average consumption baskets, and aggregate production data (Adam, 2011; Fuceri et al., 2016; Meyimdjui and Combes, 2021; Okou et al., 2022; Arndt et al., 2023). but there is also a literature looking at household level impacts of the post-2008 price shocks (see for example, (Ivanic and Martin, 2008; Fruttero et al., 2011; Nicita, 2009). Important contributions to this work in the context of price shocks in the post-pandemic era include Okou et al. (2022), who explore the determinants of domestic retail staple food prices in sub-Saharan Africa, highlighting the importance of import dependence for the extent of price pass-through, and Arndt et al. (2023), who use national economy-wide models to measure the near-term impacts on poverty and food insecurity of the price shocks induced by the war in Ukraine.

Much less attention has been paid to within-country spatial effects of external price shocks, which is where this paper contributes. Important contributions in this area include empirical work by Cudjoe et al. (2010) who develop an empirical analysis of spatially differentiated price transmission in Ghana, and Arndt et al. (2008) who use a CGE model for Mozambique that allows for a simple rural-urban distinction in household incomes and consumption, although not in production and distribution. The work of Baptista et al. (2023), which is probably closest to the current paper, develops a similar spatial general equilibrium model to examine the impact of climate shocks to agricultural productivity, as opposed to external price shocks, on spatial patterns of production and consumption.

Our work also connects to the growing literature that focuses on the importance of spatial frictions within countries. Some of this work focuses specifically on transport costs and frictions (Atkin and Donaldson, 2015; Donaldson, 2018; Gollin and Rogerson, 2014; Sotelo, 2020; Farrokhi and Pellegrina, 2023; Pellegrina, 2022; Gaigné and Gouel, 2022). Other literature emphasizes market integration more broadly (Allen, 2014; Moser et al., 2009; Campenhout, 2007; Burke et al., 2019). A few papers address more narrowly the role of market integration for shock transmission and food insecurity (Burgess and Donaldson, 2012; Janssens et al., 2020; Gao and Lei, 2021; Simola et al., 2022).

The remainder of this paper is organized as follows: Section 2 discusses potential mechanisms through which global price shocks affect consumer welfare in LICs and provides an overview of possible policy instruments. Section 3 presents our modelling framework, with full details contained in Appendix B, while Section 4 describes the empirical setting of this study, briefly summarizing Tanzania's exposure to global price shocks and spatial patterns in the domestic economy, and briefly describes the calibration procedures and the baseline equilibrium. Section 5 presents the application to Tanzania and discusses the results of the different policy experiments. Section 6 concludes.

2 Global price shocks and their local effects in LICs

Commodity price volatility, punctuated by occasional large price spikes, is a recurring feature of the global economy. Figure 1 plots price indices for food, fuel, and fertilizers over time. The left panel shows price developments since 2006, including the three 'global food price crises' that have occurred this century in 2007, 2011, and 2022. The right panel zooms in on price developments since 2019, showing the sharp simultaneous increase in the global prices of food, fuel and fertilizer observed in 2021 and 2022. This increase was initially driven by recovering aggregate demand as economies reopened after the COVID-19 shock; but in early 2022, price increases accelerated drastically due to the effects of the war in Ukraine. The war triggered a strong negative global supply shock, as both Ukraine and Russia were important exporters of agricultural products, energy commodities, and raw materials used in fertilizer production.

Rising global prices for food, fuel, and fertilizers exert pressure on the balance of payments of all net importers of these commodities, with the effects typically stronger in LICs, where import dependency is high, demand elasticities are low (with many households are living at near-subsistence levels of consumption), and where the capacity for offsetting macroeconomic policy responses is limited.

Transmission of global prices to the domestic economy occurs through a number of channels. First, fertilizer price increases directly impact the cost of agricultural production, for both staple crops and cash crops. The impact on production and on consumer prices depends on the tradability of commodities and on farmers' capacity to substitute away from imported fertilizer use in production.

Second, rising food prices directly impact households' food expenditure, all else equal. The

Figure 1: Global prices of food, energy and fertilizer

Source: World Bank Commodity Price Data (retrieved February 17, 2023). All series are scaled by US CPI deflator (FRED, all consumers). Series in right panel are in logs with scale representing percentage change relative to January 2019.

magnitude of this price effect depends on households' dependence on imported foods and more broadly on their income levels and net food production. For poor urban households, the effects may be especially acute, since these households purchase most of their food (rather than producing it) and food expenditure constitutes a large share of the total expenditure for the poor. On the other hand, net food-producing households in rural regions may be positively affected by higher global food prices if these (partially) pass through to prices for domestically produced food, and if the revenue increase from sales offsets the cost increase for their consumption of directly imported food.

Finally, higher fuel prices drive up the cost of transporting and distributing food, both internationally and domestically.[3] In many LICs, which typically face high domestic trade frictions, transport costs constitute a significant share of final consumption prices for imported foods in remote rural regions – and symmetrically for domestically produced foods sold in urban areas.[4] In addition, higher transport costs put negative pressure on export earnings of cash crop producers in these rural regions, further lowering their ability to purchase food.

[3]Where agriculture is mechanized, higher fuel prices also influence the cost of food production. Mechanization in agriculture is typically lower in low-income countries, but this effect on food production in higher-income food exporters can have noticeable second-round effects on the price of imported food.

[4]For example, Atkin and Donaldson (2015) find that that "the effect of log distance on trade costs within Ethiopia or Nigeria is four to five times larger than in the US".

2.1 Policy responses to price shocks

In the face of global price shocks, and motivated both by concerns over poverty and income distribution and by pressures from interest groups, governments can and frequently do implement short-term reactive measures aimed at mitigating the imminent effects of realized shocks, and longer-term precautionary or adaptive measures aimed at reducing vulnerability to future shocks. Such longer-term measures consist mostly of structural reforms in agriculture, infrastructure investments, and trade or financial sector reforms (e.g., strengthening insurance markets).[5] The focus of this paper is exclusively on short-term mitigation responses.[6]

In terms of mitigation measures, a distinction can be drawn between those measures aimed at directly supporting vulnerable households while letting prices largely pass through to the domestic economy, and those that seek to moderate or fully offset the forcing external price shocks themselves. The former include direct and indirect cash transfers, in-kind support, and food vouchers; the latter category might include changes to specific subsidies and/or tariffs on intermediate or final goods. The relative welfare effects of different policies will depend, *inter alia*, on whether the forcing price shocks are temporary or persistent; on the capacity to identify and implement social safety nets for vulnerable households; on the capacity to accurately target subsidies and tariffs; and on the extent to which both sets of measures can be unwound when temporary price shocks pass.[7]

In response to the price spikes in 2022, countries at all income levels adopted policies intended to mitigate the effects of the higher prices (Figure 2). Advanced economies tended to use cash transfers and semi-cash transfers, although some also introduced un-targeted tax and spending measures including reductions in consumption taxes, or price freezes. In contrast, many emerging economies and low-income economies had less fiscal scope for such policies; these countries tended to opt instead for tax cuts, price freezes and subsidies, and policies targeting trade (e.g., through customs duties and trade restrictions).

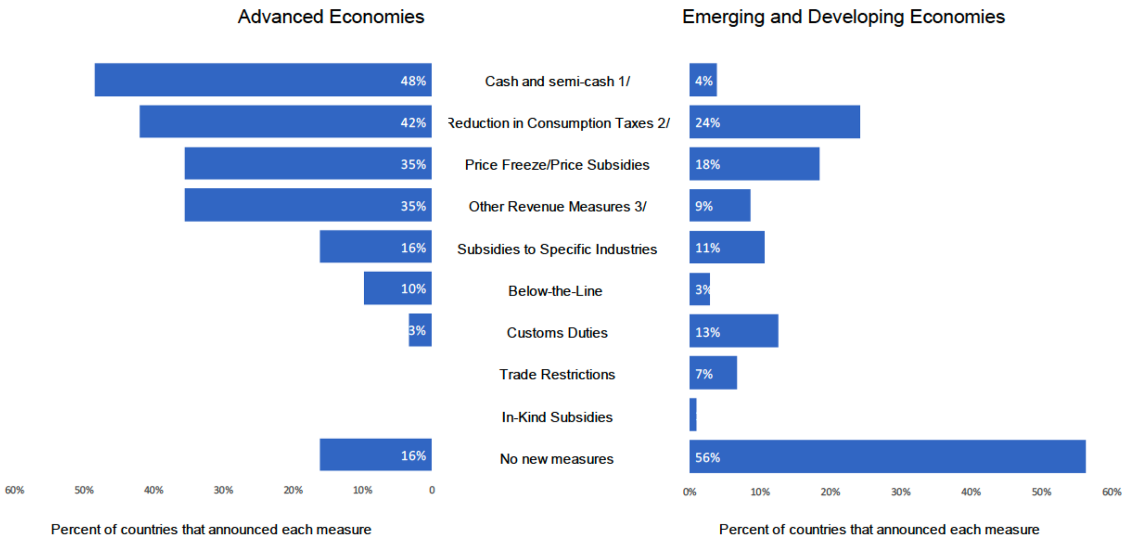
To analyze the impact of the price spikes and policy responses, we need a model that can usefully represent these varied channels of price transmission into the domestic economy. We also need a model that permits us to represent the different policy responses in convincing ways. To combine these ingredients, we build on a model framework from Adam et al. (2018).

[5]For a comprehensive discussion of such reforms in the context of climate change and chronic food insecurity in sub-Saharan Africa see Baptista et al. (2022).

[6]See also (Amaglobeli et al., 2022).

[7]Conventional wisdom and holds that income-transfer based measures may be preferable to trade policy measures if the latter block domestic relative price adjustments and therefore distort efficient resource allocation. However, if price shocks are temporary and adjustment costs are non-trivial, the arguments against price-based measures are weakened.

Figure 2: Policy measures announced in response to price spikes since 2022



Note: "No new measures" refers to countries that responded to the survey and have not announced any measures. 1) includes cash transfers and semi-cash, such as vouchers and utility bill discounts. 2) includes value-added and excise taxes. 3) includes changes to income taxes and other revenue measures. Source: Amaglobeli et al. (2022). IMF staff estimate based on an IMF survey of 134 countries (31 advanced economies and 103 emerging and developing economies) conducted in March 2022 on the measures taken by governments since 2022 in response to rising food and commodity prices.

3 Model structure

Our model is a dynamic multi-sector, multi-household, spatial general equilibrium model of a small open agricultural economy. In this section, we describe the main features of the model. The full equation listing of the model is relegated to Appendix B.

3.1 Production and Consumption

The model distinguishes four stylized locations: a remote ('far') rural economy involved in staple and cash-crop agriculture; an adjacent ('near') rural region, which trades with both the far rural region and the principal urban center; an urban center, which trades with the near rural region and with the rest of the world; and finally, the rest of the world (see Figure 3 and Table 1). Goods or services are location-specific, both in production and consumption. Hence on the supply side we distinguish nine spatially-differentiated sectors of production: the two rural regions each produce a staple food crop and an export cash crop, along with local non-tradable services. Manufactured goods, processed food and local non-tradable services are produced in the urban region. The model combines goods that are traded across both internal and international boundaries, those that are traded internally and those that are locally non-traded. Internal and international trade (and hence market structures) reflect the cost of transporting goods between these locations, with the transport cost wedge reflecting route- and commodity-specific fuel costs and a corresponding mark-up over cost by the domestic monopoly supplier of transport services. Domestic production is complemented with 'competitive' imports of processed food and manufactured goods and with non-competitive imports of fuel and fertilizer.[8]

The economy is a price-taker in world markets for tradable goods (processed food, manufactures, fuel, and fertilizer) and for the economy's export good (the cash crop). These international prices are 'quayside' prices, i.e. cif prices but before tariffs, duties or subsidies, and are denoted in foreign currency. The model thus captures the principal pass-through channels noted above from global food, fuel and fertilizer prices to: (i) border prices for export cash crops and (ii) non-traded staple food crops (via fertilizer and domestic transport costs); and (iii) to final consumption of tradable processed food and manufactured goods (directly and through intermediate input costs). It is also able to track pass-through effects to the non-food economy, both through transport costs and, indirectly, through real exchange rate effects on the structure of domestic production and consumption.

Figure 3: Schematic overview of the model geography

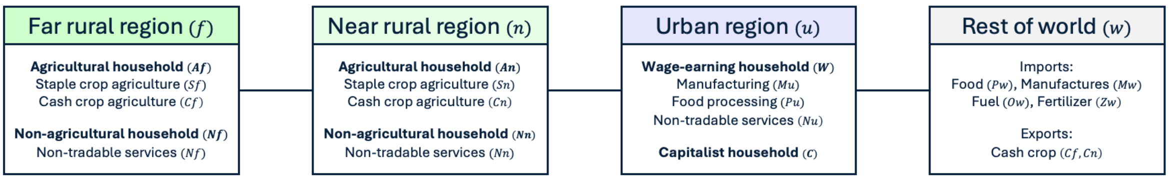


Table 1: Household types

Location	Household	Factor Endowment	Sector	Factor income	
Far (f)	Agricultural (A)	Labor, land	Staple crop	w_{Sf}	wage
				b_{Sf}	land rents
			Cash crop	w_{Cf}	wage
				b_{Cf}	land rents
	Non-agricultural (N)	Labor	Non-tradables	w_{Nf}	wage
Near (n)	Agricultural (A)	Labor, land	Staple crop	w_{Sn}	wage
				b_{Sn}	land rents
			Cash crop	w_{Cn}	wage
				b_{Cn}	land rents
	Non-agricultural (N)	Labor	Non-tradables	w_{Nn}	wage
Urban (u)	Wage-earning (W)	Labor	Food processing	w_u	wage
			Manufacturing	w_u	wage
			Non-tradables	w_u	wage
	Capitalist (C)	Capital	Food processing	r_u	capital rents
			Manufacturing	r_u	capital rents
			All sectors	ψ_j	transport rents

Production in all locations occurs under conditions of competitive markets and constant returns to scale.[9] Agricultural production of staple and cash crops in the rural regions (far

[8] There is no intrinsic limitation to the degree of spatial disaggregation the model can handle, subject to the restriction that each good-location pair is unique.

[9] Models in the DIG tradition following Buffie et al. (2012) will typically assume constant returns to private factors but allow for increasing returns in the presence of public infrastructure capital.

and near) combines land (A), labor (L) and imported fertilizer (Z) as factor inputs. To reflect limited substitutability opportunities of labor for fertilizer inputs in agricultural production we combine these two inputs as a composite in a two-level CES production function with land (A). We assume that land allocations are fixed in the short run so that returns to land can vary across locations and crops.

Production of tradable goods in the urban region (manufactured goods, Mu, and processed food, Pu) occurs under Cobb-Douglas conditions with labor (L) and capital (K) as inputs. In the case of processed food, production also requires intermediate inputs of staple crops supplied by the domestic rural economy and of manufactured goods. The staple crop input is a CES composite of staples food produced in the far and near regions, while the manufactured input is similarly a CES aggregate of domestic and imported varieties of the manufactured good.

In each of the three regions there also exists a sector that produces local non-tradable services (N). The production of these non-tradable services is linear in labor, the single factor of production.[10]

The model features six representative household types which differ by location and factor endowments (Table 1). With the exception of the capital-owning household, which resides in the urban area, all households are populated by a representative hand-to-mouth consumer whose income derives from their ownership of land and/or labor. Total factor incomes are taxed but are then augmented by direct income transfers from the government. The capitalist household, by contrast, owns the physical capital in the economy and has monopoly ownership of the transport sector. Gross profits and monopoly rents from transport are taxed. In addition to investing in the manufacturing and food processing sectors, the capitalist household holds government bonds (the income from which is un-taxed) and makes net remittances overseas.

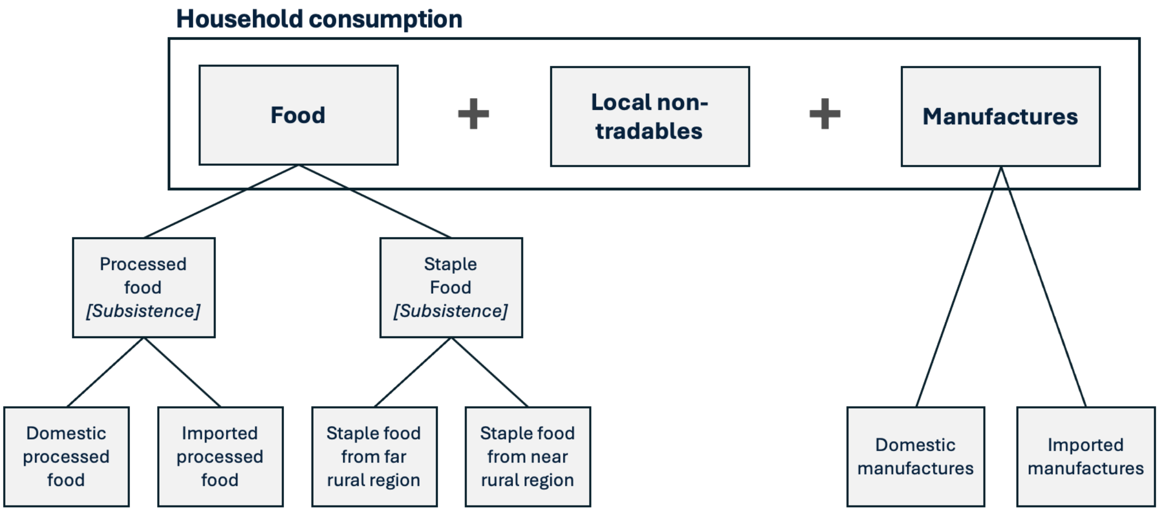
All six households consume staple and processed food, manufactured goods and their local non-tradable service. Consumption is modeled as a three-tier nested CES structure to reflect all key margins of substitution, both between different goods and between different varieties of the same good (see Figure 4).[11] Total consumption for each household is thus a CES aggregate of a composite food good, a composite manufactured good, and region-specific non-tradable services. The food composite is, in turn, a combination of processed food and staple foods. Finally, at the lowest level, processed food and the manufactured good is a composite of domestically produced and imported varieties, while the staple food is a composite of staple foods produced in the near and far regions. Subsistence requirements on food generate non-homotheticicities in consumption. At high levels of aggregation, as for example in the Buffie et al. (2012) two good model, the elasticity of substitution is generally small (they uses

[10]It is straightforward to allow for diminishing returns to labor in the non-tradable services sector.

[11]Although consumption shares differ across households, we assume a common set of substitution elasticities between goods.

0.5). At higher levels of disaggregation, elasiticities of substitution between imported and domestic varieties are typically larger, ranging between 1 and 3 for agricultural goods and 2 and 5 for manufactured goods (see for example the work by Arndt et al. (2023) based on standard IFPRI models). In the current simulations we set all elasticities of substitution at 1.5, towards the lower end of estimates used in multi-sector models.

Figure 4: Schematic overview of consumption



3.2 Transport costs

The movement of goods between regions is costly, generating a wedge between the factory- or farm-gate price at the origin (p_j^x) and the consumption price at the destination (p_j^y), where x and y denote origin and destination, respectively. The transport cost wedge consists of two components: (i) direct fuel costs and (ii) transport rents that accrue to the capitalist household in the urban region. The consumption price at destination is thus:

$$p_j^y = p_j^x(1 + \underbrace{\psi_{ij}^{rent}}_{\text{rent}}) + \underbrace{\psi_{ij}^{fuel}}_{\text{fuel}}.$$

The rent component of transport costs is a simple proportional mark-up on the price at origin. The fuel cost component is the cost of fuel required to move on unit of the commodity between origin and destination. The unit cost of fuel is defined as $(1 - s_O)Ep_O^w\vartheta_{ij}$ where s_O is the fuel subsidy, p_O^w is the c.i.f. international price of imported fuel, E is the exchange rate, and ϑ_{ij} is the per-unit fuel requirement to move one unit of the commodity from origin to destination. Both the per-unit fuel requirement (ϑ_{ij}) and rent (ψ_{ij}^{rent}) are indexed by ij to indicate that they vary by commodity and trade dyad. Trade between the urban region and the far rural region moves via the near rural region. For simplicity we assume that transport costs are symmetric around the near rural location, such that goods transported between near and far, and goods transported between near and urban are subject to the same transport costs. We also assume that within-region trade is frictionless so that $\psi_{ii}^{rent} = \psi_{ii}^{fuel} = 0$.

3.3 Fiscal Balance

The government raises revenues through taxes on factor incomes from all households, export duties on cash crops, and tariffs on (imported) manufactured goods. It also receives donor-determined unrequited aid flows. On the expenditure side, the government spends on direct cash transfers to the non-capitalist households, on subsidies (on fuel and fertilizer imports) and on domestic and external debt service. Conditional on external financing flows (consisting of unrequited aid flows or concessional debt financing), fiscal balance is restored through adjustments to taxes and/or transfers to households. Adjustments to fiscal policy are defined in terms of a set on simple rules. In the spirit of (Buffie et al., 2012), however, we assume that taxes and transfers adjust with a lag so that the fiscal balance is satisfied period-by-period through net sales of domestic debt to the capitalist household.

3.4 External Balance and Model Closure

External trade is subject to import tariffs and export duties. The economy imports foreign varieties of both processed food and manufactured goods. In addition, it sources fertilizer and fuel, two non-competitive imports, from the rest of the world. Cash crop production in the two rural regions is exported in full and is sold at given world prices.[12] The overall trade balance is financed by net private foreign capital inflows, official grants and concessional debt inflows. In the application reported below, all sources of external finance are determined exogeneously, which means the external balance is brought about through the balance of trade and hence is sustained by adjustments to the real exchange rate.[13]

Commodity markets clear in each period, i.e. there is no storage of goods across periods, and labor markets clear within region, i.e. there is no migration between regions. Within a given region, however, labor is perfectly mobile across sectors.

4 An Application to Tanzania

To illustrate the insights this model can generate, we examine the impact of recent global price shocks on the United Republic of Tanzania, a country characterized by a large agricultural sector, high internal trade frictions and strong spatial heterogeneity in production and consumption.

[12] In the empirical application to Tanzania, in order to match the country's balance of payments data we also include an exogenous volume of natural resource exports which is held constant over time and across simulations. These represent production of gold and international tourism. Although in reality the tourism sector generates some upstream and downstream effects, we assume here for convenience that both tourism and gold are produced in wholly foreign-owned enclave sectors so that the net output of these sectors consists entirely of exports.

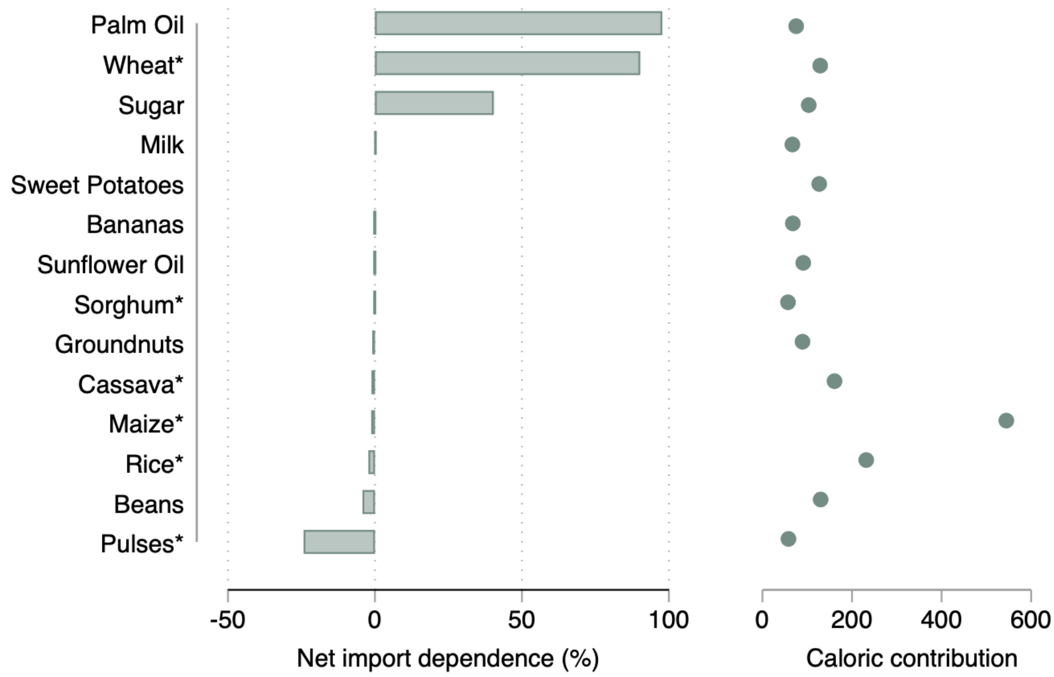
[13] Formally, this is a Johansen closure (Johansen, 1960). It is, of course, possible to solve the model under alternative closures, including allowing external finance to be determined endogenously.

We start this section by describing the structure of Tanzanian's economy and then briefly discuss the calibration of the model to the key features of the economy. In Section 5 we explore the properties of a set of counterfactual policy simulations. Although the model is stylized and the representation of the price shocks is necessarily also somewhat crude, the model does a good job of representing important features of the data, giving us confidence that our counterfactual scenarios might also be informative.

4.1 Food Price Shocks, Spatial Heterogeneity and Policy Responses

While Tanzania has a balanced net food production position in aggregate (Baptista et al., 2022, Figure 2), import dependence for some (mostly processed foods) is very high (see Figure 5), whereas for other types of food (mostly starch staples), Tanzania is self-sufficient or even a net exporter. In addition, the country is almost entirely dependent on imports for fuel and synthetic fertilizer. These features of the Tanzanian economy are shared across many low-income economies, and especially those of sub-Saharan Africa.

Figure 5: Food – Net import dependence and caloric contribution



Note: * category includes products derived from named product, e.g. 'Wheat*' refers to 'Wheat and products'. Net import dependence is calculated as 100*(imports-exports)/(production+imports-exports). Caloric contribution refers to FAOSTAT's 'Food supply (kcal/capita/day)' variable. Net import dependence and caloric contribution are mean values for the years 2010-2020. This figure only shows foods with a caloric contribution of at least 50 kcal/capita/day. Source: FAOSTAT Food Balance (Feb 20, 2023)

Tanzanian data reveal strong spatial patterns in poverty, economic activity and consumption. This spatial heterogeneity matters critically for households' vulnerability to global price shocks. As Figure 6 shows, food consumption patterns vary significantly across space. Households in rural regions consume more domestically produced traditional staples like maize, cassava, and sweet potatoes. Urban households consume higher quantities of processed foods, such as cooking oil and sugar. These different consumption patterns imply a differential exposure to global price shocks, as a higher consumption share of processed foods in urban regions implies a higher dependence on imports.

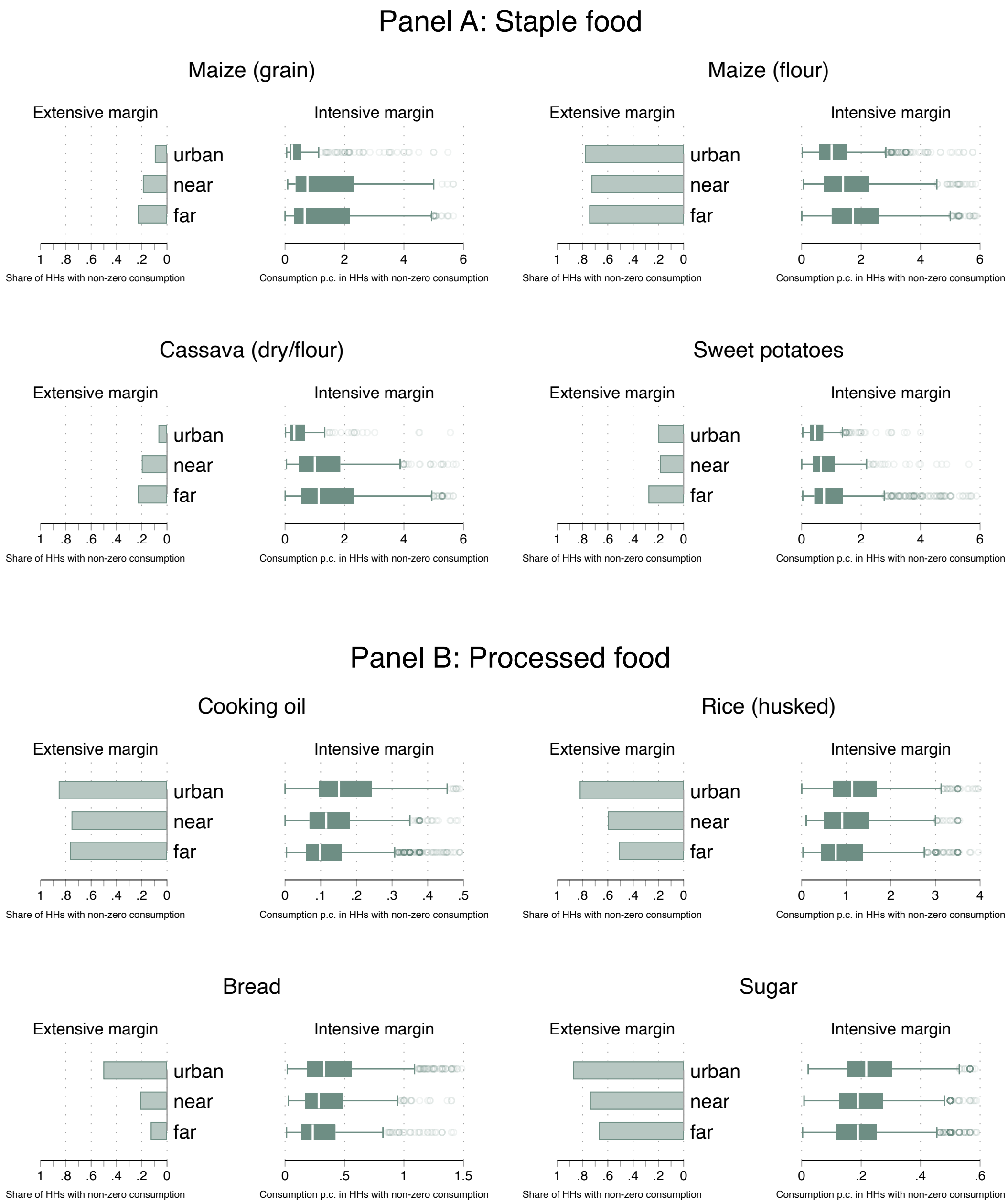
Finally, in response to the recent global price spikes, Tanzania has implemented different measures to insulate the domestic economy from the effect of these shocks. These policy measures include "(i) providing targeted and temporary subsidies for the import of petroleum products via the waving of excise duties, (ii) reducing import duties on cooking oil by lowering important duty rates for refined edible oil and crude cooking oil, (iii) introducing fertilizer subsidies to support producers of agricultural products and fertilizers to boost local production and substitute part of the imports, and (iv) waiving of VAT for locally produced fertilizers and reduction of royalty charges on minerals used in the energy and fertilizer industries" (Rother et al., 2022, p. 30).

4.2 Calibration of baseline equilibrium

Baseline calibration relies on a blend of aggregate macro data and high-quality geo-referenced micro survey data. The principal anchor for the calibration is the 2018 Social Accounting Matrix (SAM) for Tanzania (Thurlow, 2021), which distinguishes 42 activities and commodities and defines 10 different household types by income deciles. Neither production nor households have an explicit spatial location. By contrast, our model features nine spatially-differentiated production sectors, 13 commodities (nine domestically produced and four imported), and six spatially-differentiated households. In order to construct a consistent map from the SAM's aggregate data to our spatial model structure, we impose a set of identifying assumptions concerning the location of production and consumption. The starting point is geo-referenced microeconomic survey data reported in the National Panel Survey (NPS) for Tanzania, which is administered in conjunction with the World Bank's program of Living Standards Measurement Studies (LSMS). The survey data give us an initial spatial distribution of production, land and labor (see Appendix D.1).[14] Next, we reshape the consumption vectors given by the SAM, assigning total household consumption of each commodity type to the six household types in our model. As there exists no way to directly map from the income deciles in the SAM to our model household structure, we again draw on NPS data to inform the mapping (Appendices D.2 and D.3). The calibration of transport cost wedges is based on Adam et al. (2018), subject to SAM control totals. Finally, fiscal and macro aggregates are based on the SAM and IMF Article IV documents and reports. The details of this calibration process and consequent spatial distribution are described in the calibration appendix (Appendix C).

[14] We use five waves of Tanzanian data from 2008-2019 (National Panel Survey data collection waves 1-4, plus the extended panel collected in 2019).

Figure 6: Consumption of staple and processed food items by region



Note: This figure shows household consumption of selected staple food items (i.e. unprocessed and minimally processed foods) and processed food items (i.e. industrially processed food items) at the extensive and the intensive margin. The extensive margin is defined as the share of households with non-zero consumption of a given food item in the 7 days before the time of data collection. The intensive margin is defined as the quantity consumed per capita in kilograms (or liters) in the 7 days before the time of data collection. Per capita consumption is approximated as total household consumption adjusted for household size as measured in adult equivalents. Households are categorized as urban, near rural or far rural based on their geo-referenced location and the GHSL degrees of urbanization. Source: LSMS, National Panel Survey (waves 1-4), food consumption questionnaires.

The structure of the economy and factor intensity of production at baseline are summarized in Table 2. Table 3 reports the fiscal and external balance at baseline.

5 Application: Shocks and Policy Responses

We now turn to simulating the impact on our calibrated version of the Tanzanian economy of the global price disruptions discussed above. To do so, we consider a stylized combined temporary shock to world prices for food, fuel and fertilizer prices (p_P^w, p_O^w, and p_Z^w), for which the local economy is a price-taker.

5.1 The price shock

For simplicity, we represent the shock to our model economy as an increase of 30% in the world prices for food, fuel and fertilizer, relative to their baseline values. We approximate the profile of the shock by assuming prices remain at this elevated level for two years before returning back to their pre-shock levels smoothly over the next three years.[15]

The global price shocks transmit to consumers and producers through three separate channels. The first is the rise in the price of fuel and fertilizer, which directly increase costs of production for producers of staple and cash crops in the two rural areas: farmers simultaneously face higher costs of fertilizer and higher costs of transporting fertilizer from the port. Given the intensity of use (Table 2), and prior to any substitution away from fertilizer use, this raises the incipient *total* costs of production by 0.5% and 1.2% for staple production in far and near locations respectively and by 0.4% and 3.6% for cash crops produced in far and near.[16] The second channel is the direct effect on the cost of imported food which accounts for approximately 10% of total consumption and approximately one quarter of total food consumption in the baseline. The third channel is the impact on the cost of moving domestically produced goods between locations for domestically and internationally traded goods.[17] Recall, as noted in Appendix C, locally non-tradable services attract no transport costs.

[15]The periodization of the model is annual, although it is straightforward to adjust the parameterization to a quarterly frequency. The model shock is smoother, more symmetrical, and smaller in magnitude than the actual global price shock observed in 2022 after Russia's invasion of Ukraine, particularly for fuel and fertilizer. (See 1 above.) Nonetheless, our characterization allows for a clean identification of the transmission of shocks without having to consider the specific profile of the individual components of the shock. It is a trivial matter to relax this simplifying assumption.

[16]The higher cost of production in near reflects that despite the lower transport costs, fertilizer is used much more intensively in production compared to the far region, where the transport cost element is higher.

[17]For reference, fuel costs account for approximately 55% of the overall transport wedge between producer and farm-gate prices and consumption prices.

Table 2: Structure of the domestic economy at baseline

	Cash crop	**Staple crop**	**Food processing**	**Manufact.**	**Non-tradables**
[1] Supply (at producer prices as share of total output of goods and services)					
Total	3.57 %	28.16 %	25.48 %	27.21 %	15.58 %
Far rural	2.15 %	20.10 %	-	-	2.64 %
Near rural	1.42 %	8.06 %	-	-	1.29 %
Urban	-	-	17.20 %	7.78 %	11.65%
RoW	-	-	8.28 %	19.43 %	-
[2] Private Absorption (at consumer prices as share of total absorption)					
Total	16.19 %	28.40 %	22.37 %	21.57 %	11.47 %
Final demand					
Far rural	-	10.48 %	6.75 %	7.26 %	1.94 %
Near rural	-	3.50 %	2.60 %	2.22 %	0.95 %
Urban	-	9.00 %	13.02 %	10.87 %	8.58 %
RoW	16.19 %	-	-	-	-
Intermediate demand					
Food processing	-	5.42 %	-	1.22 %	-
[3] Factor intensity (per unit of output)					
Labor					
Far rural	0.197	1.352	-	-	2.206
Near rural	0.233	1.284	-	-	1.500
Urban	-	-	0.437	0.364	0.728
Land					
Far rural	0.098	0.258	-	-	-
Near rural	0.058	0.201	-	-	-
Capital					
Urban	-	-	3.613	4.517	-
fertilizer x 100					
Far rural	0.106	0.695	-	-	-
Near rural	3.035	3.106	-	-	-

Note: [1] Total supply *excludes* fuel and fertilizer imports. Supply is reported as a share of total output at producer prices (total supply is 138% of GDP). [2] Final demand and intermediate demand are reported as a share of total absorption at location-specific consumer prices (total absorption is 188% of GDP at factor prices). [3] Factor intensity is reported per unit of output in quantity terms, so comparisons are only meaningful within commodity type.

Table 3: External and fiscal balance at baseline

External balance	% **Value added**	**Fiscal balance**	% **Value added**
Total Exports	17.2 %	**Total Revenue**	28.4 %
Cash crop – far	12.9 %	Tariffs	3.8 %
Cash crop – near	4.4 %	Export duties	1.7 %
Total imports		**Total Expenditure**	30.4 %
Processed food	13.0 %	Subsidies	2.4 %
Fuel	21.5 %	Transfers	25.9 %
Fertilizer	0.9 %	Debt service	2.2 %
Manufactures [a]	23.9 %	**Deficit**	2.0 %
Manufactures [b]	1.3 %		
Manufactures [c]	5.1 %	Aid	2.0 %

Note: Total value added at baseline is 98.8 (domestic production at producer prices plus fertilizer imports at farm-gate prices). [a] Manufactures imported for final consumption. [b] Manufactures imported for use as intermediates in the domestic production of processed food. [c] Manufactures imported for capital formation.

5.2 Benchmark: price shock with no policy response

The first step in the analysis is to define a benchmark against which to assess the impact of policy measures. This is not trivial, since some choice needs to be made over the fiscal and external closure of the model. For the benchmark we assume a setting in which tariff, subsidy and tax rates are kept unchanged and where there is no additional external financial inflows from either public or private creditors in response to the price shock. External balance is therefore restored following the shock through adjustments in the balance of trade. On the fiscal side, to the extent that the shock to relative prices alters the tax base, the fiscal balance is restored by residual adjustments (in this case reductions) to total government transfers to the non-capitalist households, pro-rated according to each household's share of transfers in the baseline equilibrium. However, since adjustments to transfers are not instantaneous, the period-by-period fiscal balance is satisfied by domestic borrowing.[18] Figures 7 to 10 provide a graphical summary of the evolution of production, consumption, public finances and domestic prices over the first 10 periods.

5.2.1 Production and employment

The price shock imparts an adverse supply shock that directly raises costs of production for agricultural goods - both for those destined for domestic consumption and for export. It also drives up the cost of imported food and the costs of distribution for all goods traded outside their production locale. But while aggregate domestic production falls (in real terms by a cumulative 4.08% of the initial value over the first five years), the effects are strongly heterogeneous. The agricultural sectors suffer significantly larger output contractions than

[18] This pattern of adjustment is thus a close approximation to a lump-sum rebate of the change in net public savings arising from the price shock.

non-agriculture, with elevated fertilizer prices increasing the costs of production in both the far and near regions and higher fuel costs increasing the cost of getting agricultural output to urban domestic markets and to world markets. The output hit – more than twice as large for agriculture as for the aggregate economy over the five-year shock period – is largest in the far region (because of higher transport costs) and for cash crops.[19] In both regions, the contraction in staple food production is substantially smaller than for cash crops, for two important reasons: the first is that the presence of subsistence consumption requirements for food puts a floor under demand and hence partially mitigates the adverse income effect from the price shock. The second is that, while costs of production for staple foods have increased, so have the costs of directly imported (processed) foods, which stimulates substitution in consumption from processed foods to domestic staple foods, on the part of all households. The same real exchange rate depreciation stimulates urban production of import-substituting processed food and manufactured goods, as substitution effects drive consumption away from imported varieties and mitigate the decline in domestic production of processed foods.

The counterpart to these demand effects on locally and internationally tradable goods is seen in the movement of labor (and hence output) towards the non-tradable sectors. In both the far and near rural regions, the adverse price shock sees labor move decisively out of cash crop production. This movement is not reflected in staple crop production; there is a small movement of labor *into* staple crop production, in both far and near regions, as farmers substitute labor for fertilizer in production.[20] This is not sufficient to offset the decline in fertilizer use, so production of staple crops falls. The net effect, however, is labor-shedding in agriculture. Given our assumption of local full employment, this means a corresponding movement of labor into the production of local non-tradable goods and services. Increased output in these sectors, combined with reduced aggregate demand, drives down the relative price of non-tradable goods in far and near.[21] By contrast, in the urban economy, the increased demand for labor in the domestically-processed food sector draws labor out of both the manufactured and non-tradable sectors, although these effects are substantially smaller given the lower labor intensity of production.

Given the model assumes flexible wages and full employment across the three (segmented) labor markets, the pattern for wages follows directly. Reflecting the decline in the value of the marginal product of labor, wages in agriculture fall over the period of the shock, more sharply in the far region than in the near, and more strongly for the non-tradable sectors.

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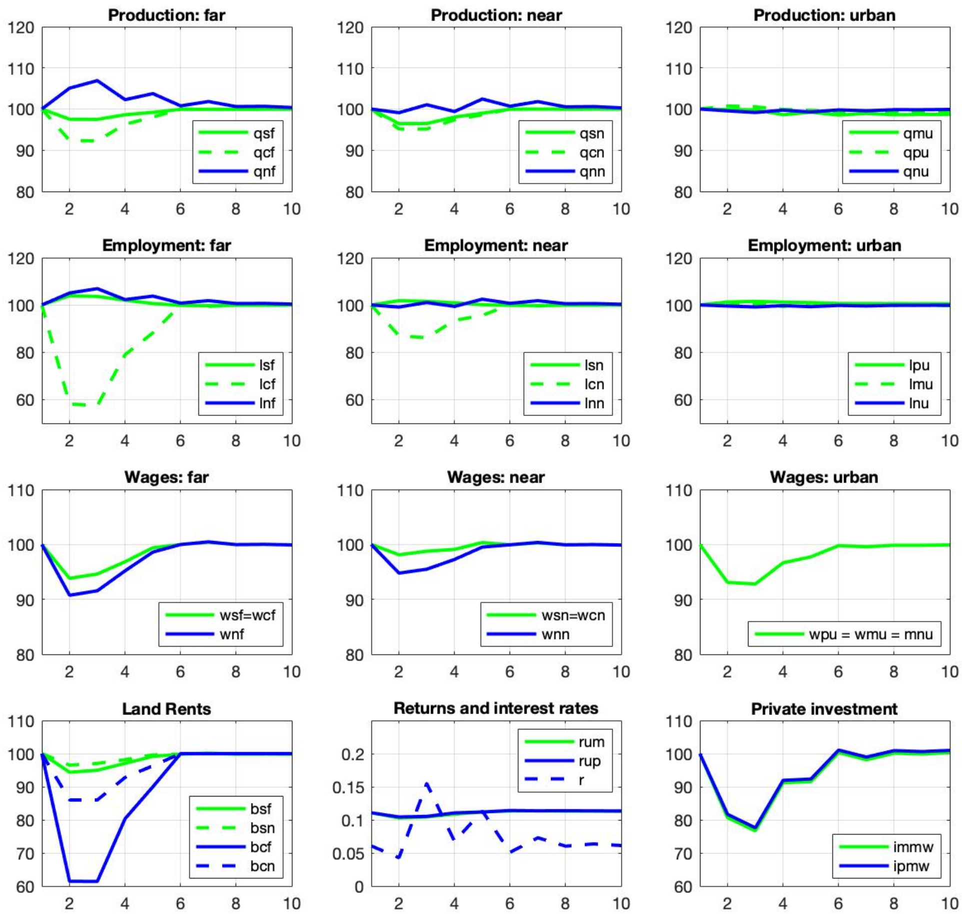
[19]We assume the price shocks do not impact the c.i.f component of export trade. In reality, domestic export producers also bear some share of increased international transport costs: our simulations therefore understate the adverse hit on cash crop exports.

[20]See equation (1) in Appendix B. Annual fertilizer use is on average approximately 16% lower across the period of the shock.

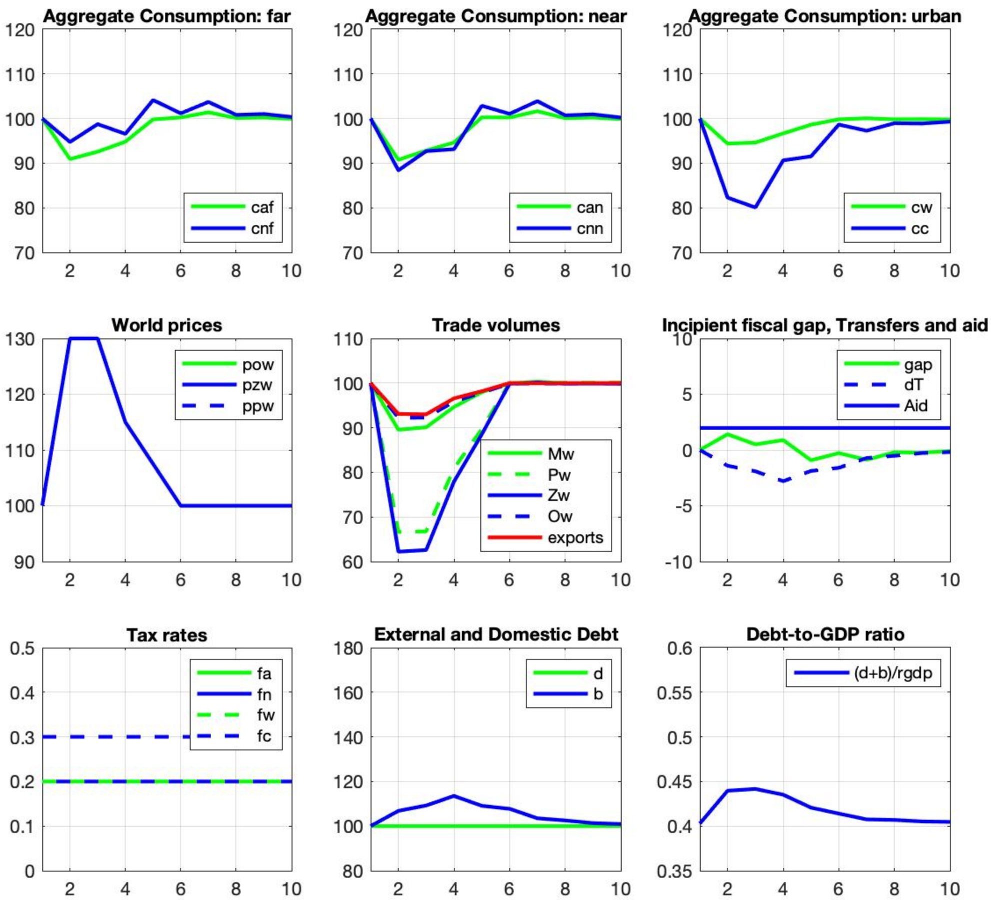
[21]Recall from equation (14) that output is linear in labor in the non-tradable services sectors. Allowing for diminishing returns to labor would dampen the supply responses in these sectors.

Figure 7: Production, employment and wages



Source: Simulation 001a. All variables, with the exception of interest rate and returns on capital are indexed to 100 at baseline. Legend notation: labels consist of three indicators. The first letter, q, l, w, b, r denotes production, employment, wages, land rents and returns on capital, repsectively; the second, s, c, p, m, and n denotes staple foods, cash crops, processed food, manufactures and non-traded good and services respectively; while the final letter f, n, and u denote far, near and urban locations.

Figure 8: Consumption, trade and fiscal balance



Source: Simulation 001a. All variables, with the exception of tax rates, the fiscal gap and the debt-to-GDP ratio are indexed to 100 at baseline. Legend notation as Figure 7 plus af, nf, an, nn, w, and c denote agricultural and rural households in far and near, urban worker and urban capitalist households respectively; pow, pzw and ppw denote world prices for fuel, fertilizer and processed food; Mw, Pw, Zw and Ow denote imports of manufactured goods, processed food, fertilizer and fuel; gap denotes the incipient fiscal gap, dT changes in transfers to households; fa, fn, fw, and fc tax rates on agricultural, non-tradable, worker and capitalist households; d is concessional external debt; and b domestic debt.

5.2.2 Income and Consumption

The income effects of the price shock are large. All the non-capitalist households experience a decline in real income, both directly from the reduction in factor prices and indirectly as a result of the fiscal adjustment – which, in this baseline case, is effected through reductions in transfers to households. Agricultural households are hit most strongly, with annual real incomes an average of approximately 3% lower for the duration of the shock. The proximate cause of declining real incomes in agriculture is the falling return to land, especially that deployed in cash-crop production. Other factors include the decline in real wages across all three sectors and the scaling back in transfers required to satisfy the fiscal balance.

The capitalist household also experiences a reduction in real income, albeit of a much smaller magnitude (the corresponding decline is around 0.6%), in this case reflecting a reduction in the real value of transport rents as the volume of internal trade declines and the decline in the gross profits, reflecting the decline in the rate of return to capital in the urban sectors and the associated decline in investment and the capital stocks.[22]

5.2.3 Fiscal and External Balances

With no adjustment to net external inflows (aid, concessional finance, and private capital inflows are held constant in the baseline), the economy's external balance is maintained through adjustments in the balance of trade. As noted above, the global price shock induces a contraction of cash-crop export volumes. This loss of export earnings, combined with increased world prices for imported fuel, fertilizer and food requires a sharp contraction in the volume of imports, achieved primarily through a compression of consumer imports (down by an annual average of 7.5% over the five years of the shock), although the degree of compression is eased in the short run by a fall in capital good imports. Fuel use also declines in quantity terms, due to the increased price and the corresponding reduction and localization of economic activity. This reduction in the quantity of fuel imports is, however, proportionally smaller than the increase in price, so the overall cost of fuel imports rises.

The shock has a large impact on the underlying fiscal balance. Subsidies on fuel and fertilizer, which are pro-rated to the cost of imports, increase in cost by around 16% per annum during the first two years of the price shock before returning back to their initial level as the price shock fades. Over the same period, revenues from tariffs decline by around 11%, while those from export duties fall by around 7% and direct taxes contract by around 8%, again before slowly returning to their baseline. This leads to a deterioration of the incipient fiscal balance over the period of the shock and entails a sharp reduction in household transfers, which fall by approximately 4% of household incomes.

5.2.4 Price dispersion

The final feature of the 'no-mitigation' simulation is how these general equilibrium responses to the world price shock transmit onto consumer prices in the domestic economy. This is not a straightforward exercise since our model is a *real* model in which we solve for the Walrasian relative prices that support equilibrium period-by-period. Price changes in this model are therefore computed relative to the model numeraire – in this case the world price of imported manufactured goods – which is held constant across the simulations. As such, the model does not reflect the evolution of the *average* price level in the economy, around which these relative prices are defined, and therefore the simulated price paths do not map directly into

[22] We assume here that although the capitalist household exerts monopoly control over the transport sector, it does not adjust rental rates on the transport sector in response to the world price shock.

empirical studies of price pass-through.[23]

Household-specific consumption price indices reflect both the composition of consumption across categories of goods and the location of production, relative to the location of consumption. Offsetting relative price effects are at work. On the one hand, processed food prices have risen for all households, and staple food prices have risen for all those households outside the far region (where households consume staple foods at local farm-gate prices that have fallen). Taken together, composite (relative) food prices have risen for all households in the urban and near locations and are nearly flat for households in far.[24] On the other hand, the adverse income effect of the shock across all households, combined with labor movements into the non-tradable sector in far and near rural areas, means the price of non-tradables has fallen relative to tradable manufactures (reflecting a real exchange rate depreciation). Finally, the price of manufactured goods rises for non-urban households and falls slightly for urban households, reflecting the substitution from imported to domestic production of manufactures. Aggregating across food, manufactures and services, relative prices rise most sharply for households in the urban and near regions and by much less in the far region and for capitalist households.

5.2.5 Summary

The results of this baseline 'no-mitigation' simulation are necessarily sensitive to the initial calibration of, among other things, consumption shares and key elasticities of substitution in production and consumption.

Nonetheless, the simulations highlight the extent to which the spatial heterogeneity in production and the presence of non-trivial transport costs implies that the impact of these global price shocks will be highly location- and group-specific. In the next section, we examine the impact of potential policy responses designed to mitigate the effects of the price shock.

5.3 Mitigation: external finance and fiscal adjustment

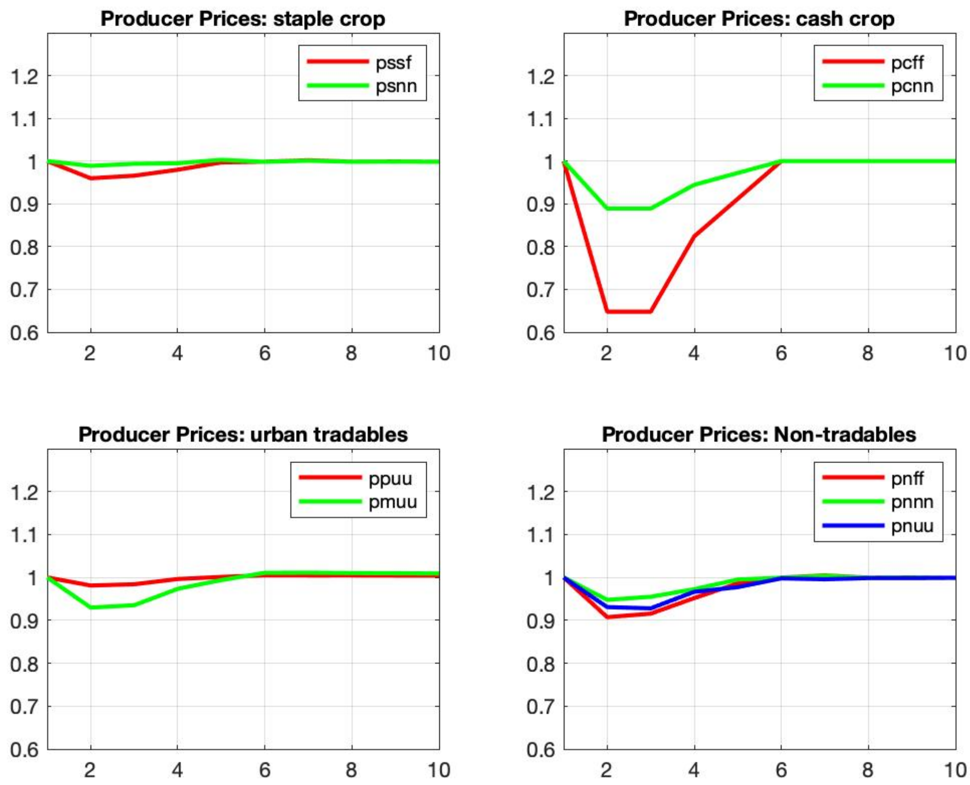
As noted above, governments in both rich and poor countries imposed a range of policies in response to the global price shocks. In this section, we consider the differing implications of different policies. We hold constant the baseline parameterization of the model, changing only those parameters that represent different policies.

Mitigation strategies have two elements: the policy response itself and the financing. For all of the policy options that we study here, we consider two variations of an 'equivalently financed' fiscal response. The first policy ('subsidies') assumes the government temporarily

[23] In principle, our results could be combined with empirical analysis on the evolution of the nominal domestic price of the numeraire, which would reflect both nominal changes in the world price of the numeraire and movements in the nominal exchange rate, to recover the implied nominal movement in consumer prices. We leave this for subsequent work.

[24] In the baseline calibration the relative share of staple food in total food is higher for the non-agricultural household so its aggregate food price actually falls.

Figure 9: Producer prices by product and location

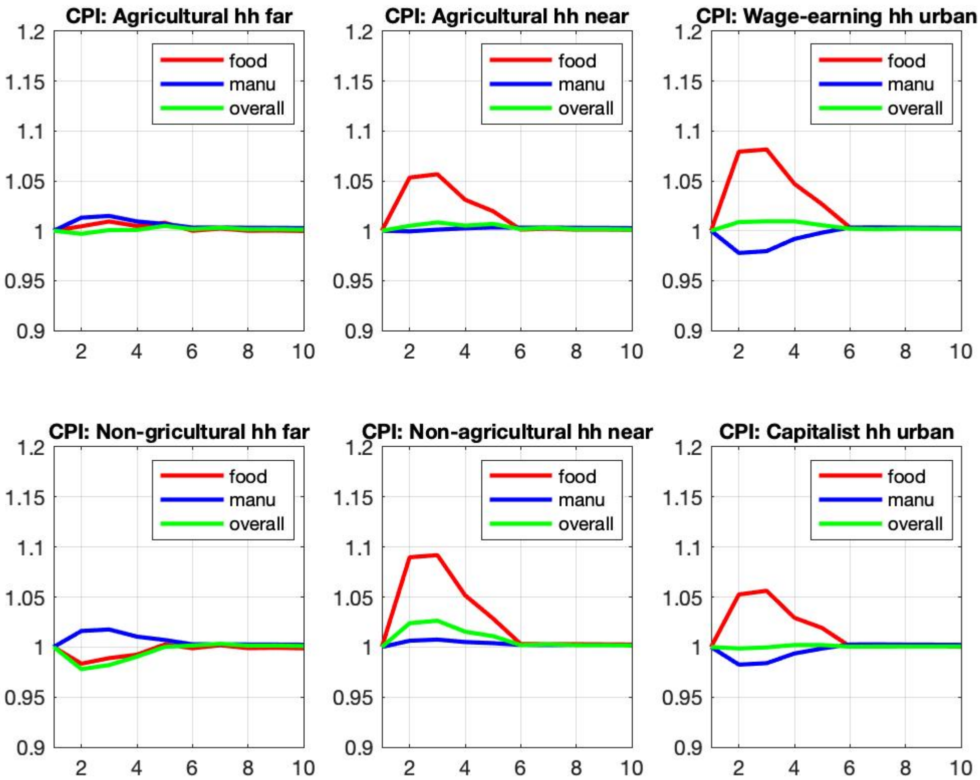


Source: Simulation 001a. Prices normalized to unity at baseline. Legend notation: $pssf$, $psnn$, $pcff$ and $pcnn$ denote farm-gate prices for staple foods (s) and cash crops (c) in far (f) and near(n) respectively. $ppuu$ and $pmuu$ denote urban factory gate producer prices for processed food and manufactured goods, while $pnff$, $pnnn$ and $pnuu$ denote location specific prices for non-tradables by location.

and credibly adjusts pre-existing subsidies on fuel and fertilizer, as well as tariffs on food imports, in proportion to the changes in world prices. The second policy ('transfers') allows world price effects to pass through to the domestic economy but seeks to protect households by adjusting the level of net transfers to the non-capitalist households. For the purposes of comparability, we assume the total value of increased transfers to households is exactly equal to the cost of the subsidy and tariff adjustments implemented under the first policy. Transfers are distributed *pro rata* with respect to household size.

The extent to which policy can lean in to the global price shock is determined by the amount of fiscal space the government can exploit, other things equal. This is governed on the one hand by access to concessional financing and on the other by the extent to which domestic taxation can plausibly be increased, and/or there is capacity for short-term domestic borrowing. On external financing we assume the following: (i) Tanzania is able to secure concessional fiscal financing through the IMF's Food Shock Window in the amount of 50% of its quota. Tanzania's quota is approximately 0.75% of GDP, and we assume the borrowing is spread over two years; (ii) it secures approximately 1.22% of initial GDP in new borrowing

Figure 10: Consumer price indices by household type



Source: Simulation 001a. Consumer prices normalized to unity at baseline.

from IDA/ADF credits, spread in a tapered fashion over three years; (iii) this is matched by equivalent sums from other concessional creditors; and (iv) it receives an increase of 0.2% of initial GDP in grant financing from bilateral development partners, again spread over three years.[25] On the domestic financing side, we focus on a scenario where there is some limited capacity to increase the tax rate; we assume that any tax increases are collected exclusively from the capitalist household.[26]

Finally, we assume that taxes cannot be adjusted instantaneously which requires that the fiscal balance is satisfied through domestic sovereign borrowing, subject to the no-Ponzi condition that the domestic debt-to-GDP ratio eventually returns to its initial level.

Figures 11 to 14 illustrate the case where subsidies on fuel and fertilizer are temporarily

[25] These figures are based on Tanzania's DSA, April 2023, Table 2, with IMF and IDA credits secured under standard terms and other concessional lending repaid over 10 years with a grace period of 5 years and at an interest rate of 5% compared to the 1.3% rate on IDA credits.

[26] Recall, the capitalist household is exposed to an overall tax rate of 30% levied on gross profits and rental income from the transport and distribution sector. This is a necessarily simplified representation of the actual tax structure: for example, while there is no tax allowance for depreciation, it does exempt interest income from taxation and there there is no withholding tax on outward remittances nor on capital inflows from overseas.

increased and the tariff on imported food temporarily reduced to partially offset the increased cost of these imports. Specifically, we first compute the fiscal cost of adjusting subsidies and tariffs to the level required to fully neutralize the increase in world prices *at baseline import volumes*. We then adjust this total amount and scale subsidies and tariffs on a *pro-rated* basis. In the simulations shown here, subsidies and tariffs are adjusted to reduce this cost by 25%. This scale of intervention sees the subsidy on fuel rise from 10% of the fob price to a maximum of 15%, while the subsidy on fertilizer rises from 25% to approximately 30%. The tariff on imported food is similarly cut, from 10% in the baseline to approximately 4% at its minimum. While these interventions moderate the impact of the shocks, the economy remains substantially exposed to the price changes, particularly since the price increases fall overwhelmingly on imported goods for which there is limited or no scope for substitution.

The first point to note is that the fiscal impact of what appears to be a relatively modest trade policy response is significant. Although supported by increased grants and concessional external finance, the additional cost of subsidies on fuel and fertilizer, the loss of tariff revenue, and the cost of maintaining household subsidies at their baseline level, together necessitate a sharp increase in the tax rate on the capitalist household. The overall tax rate rises, at its maximum, by 9 percentage points above the baseline tax rate of 30%, before converging back to baseline as subsidy and tariff rates return to their original levels. The tax rate remains above its baseline significantly beyond the end of the price shock, in order to finance the higher accumulated stock of public debt (Figure 12).

On the supply side, by reducing the scale of the price shock, the tax and subsidy policies moderate the changes in production and reallocation of labor observed in the no-mitigation case (Figure 11). In particular, the less severe increases in transport costs and the costs of fertilizer reduce the induced contraction of cash crop production in both near and far regions – and thus moderate the shift of resources into non-tradable sectors in both locations. The absolute and proportional impact on urban production is also much more muted, as this region is less dependent on transport costs and is not exposed directly to changes in fertilizer prices, although the more muted increase in the cost of imported food reduces the previous boost enjoyed by producers of domestic foods. In terms of supply, therefore, the policy measures serve to smooth the shock but without radically altering the spatial features noted earlier.

The subsidy and tariff policies generate very large differential effects across household types, however, partly as a result of the differential public finance effects (Figure 12). If subsidies and tariffs are the central policy tools, and if household transfers are held at baseline levels, the welfare gains to the non-capitalist households are unambiguously favorable, compared to the no-mitigation case. Average annual real *per capita* consumption is around 1.2% higher for non-urban households through the first five years following the price shock, while consumption of the urban worker household is approximately 0.5% higher. By contrast, the concentration of the financing burden on the capitalist household reduces real consumption, relative to the no-mitigation case. The capitalist household loses approximately 1% per annum in consumption at all horizons, through the shock and beyond, as the excess burden from higher taxes outweighs the gains that otherwise accrue to the capitalist households via improved profits and rents generated from higher domestic production, consumption and trade.[27] To account for the differential time profiles of consumption across households, we summarize the welfare effects of both the shock without mitigation and the purposive policy response, as defined in equation (23) in Appendix B, in Table 4. What emerges from this summary is that while all households are adversely effected by the shock the welfare impact is particularly strong in agricultural households dependent on the domestic and international tradability of their output. This impact is moderated for households whose income accrues, in whole or in part, from the production and sale of non-tradable goods and services.

To summarize: a partial fiscal response, funded at the margin by increased taxation on the capitalist household, provides a modest degree of relief to all non-capitalist households – much stronger for those in the far region than elsewhere – but shifts the burden onto the capitalist household. However, as the final row of Table 4 shows, welfare effects depend crucially on financing. If the marginal tax burden is spread across all households to finance the same adjustment to subsidies and tariffs, the tax increase on the capitalist household is scaled back dramatically (from around 39% at its maximum to 33.75%) while that on non-capitalist households increases from 20% to a maximum of 22.5%. This modest re-distribution of income flips the earlier result: the consumption path for the capitalist household is now unambiguously more favorable, while that for the non-capitalist households is decisively unfavorable.

Table 4: Household Welfare Comparisons

	Household					
	Far		**Near**		**Urban**	
	Ag	**Non-Ag**	**Ag**	**Non-Ag**	**Worker**	**Capitalist**
Baseline [1]	164.42	156.84	180.60	150.20	250.68	456.68
No Mitigation [2]	163.76	156.81	179.88	149.67	249.89	451.24
Subsidies [cap] [3]	163.91	156.93	179.88	149.71	249.95	449.50
Subsidies [all] [4]	163.43	155.84	178.96	148.08	249.37	453.17
Difference [pct]: [2] v [1]	-0.40	-0.02	-0.40	-0.35	-0.32	-1.19
Difference [pct]: [3] v [2]	0.09	0.08	0.00	0.02	0.02	-0.38
Difference [pct]: [4] v [2]	-0.20	-0.62	-0.51	-1.06	-0.21	0.42

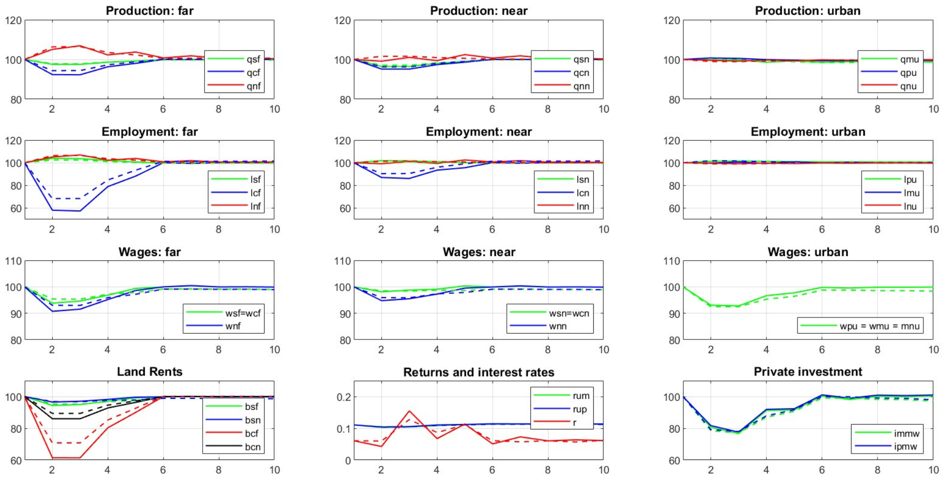
Notes: Welfare measured on basis of household-specific utility function with inter-temporal elasticity of substitution $\tau = 1.5$ and $\beta = 1/(1+r) = 0.9428$. [1] No shock baseline; [2] No-mitigation, Simulation TzaD_run_001a.mat; [3] Mitigation with subsidies and tax burden solely on capitalist household, Simulation TzaD_run_12a_slowtax.mat; [4] Mitigation with subsidies and tax burden spread across all households, Simulation TzaD_run_12b_slowtax.mat.

5.3.1 Subsidies versus Transfers

We conclude this section by examining an alternative policy response to the price shock, where instead of using trade policy measures to moderate the transmission of world prices

[27] Notice, however, the consumption profile for the capitalist household also reflects its inter-temporal optimization, so that the larger reduction in consumption also reflects, in part, the higher accumulation of claims against government.

Figure 11: Partial subsidy increase: production, employment and wages



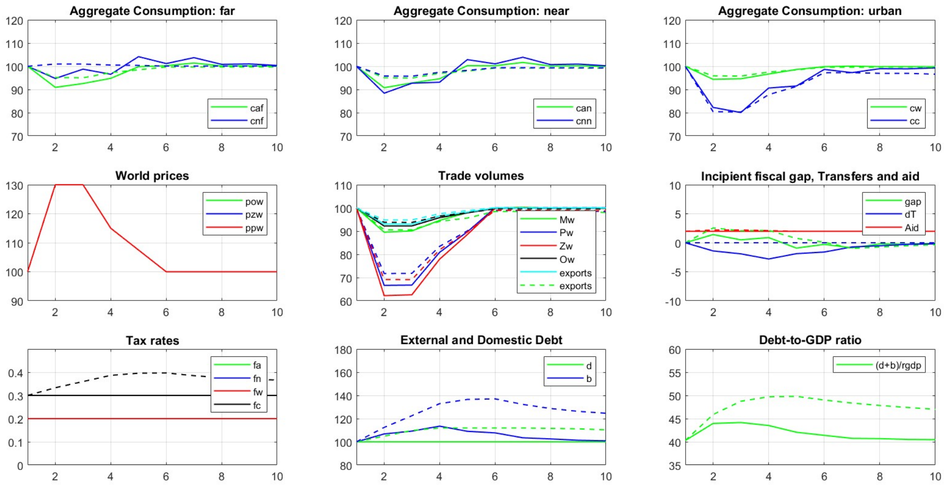
Source: Simulation 012as vs 001a. Solid lines denote path without mitigation while dashed lines indicate path with mitigation. Legend notation: labels consist of three indicators. The first letter, q, l, w, b, r denotes production, employment, wages, land rents and returns on capital, repsectively; the second, s, c, p, m, and n denotes staple foods, cash crops, processed food, manufactures and non-traded good and services respectively; while the final letter f, n, and u denote far, near and urban locations.

to the domestic economy, the authorities let world price effects pass through to the domestic economy unencumbered but seek to provide an equivalent-valued fiscal support by way of direct income transfers to households, with the total level of support allocated *pro rata* with baseline transfers. As above, we focus on the case where the domestic tax burden falls exclusively on the capitalist household. Figures 15 and 16 and Table 5 summarize key features of the comparative performance under the two policy responses.

In broad terms, since the two interventions are equivalently scaled, the differences between them are modest. Nonetheless, the switch in mitigation strategy does have important implications, primarily for public finances, consumption and welfare. On the supply side, while both strategies moderate the fall in aggregate output relative to the no-mitigation case, the moderation is greater under subsidies compared to transfers (Table 5, Panel (a)). Measured over the first five-year period following the shock, the cumulative annual output loss relative to the no-shock baseline is approximately 3.67% under the subsidies strategy compared to 4.15% under transfers. This aggregate outcome masks strongly different responses across locations. On the one hand, without the relative price protection afforded by subsidies, domestic production of tradable goods – staple and cash crops, processed foods and manufactures – falls by more under a transfers mitigation policy, while the output of local non-tradables rises by more. This is particularly pronounced in both far and near rural areas where the larger contraction in agricultural production releases relatively more labor into the production and hence consumption of local non-tradables.[28]

[28]The percentage changes in the output of local non-tradables in the rural areas reflect the relatively

Figure 12: Partial subsidy increase: consumption, trade and fiscal balance



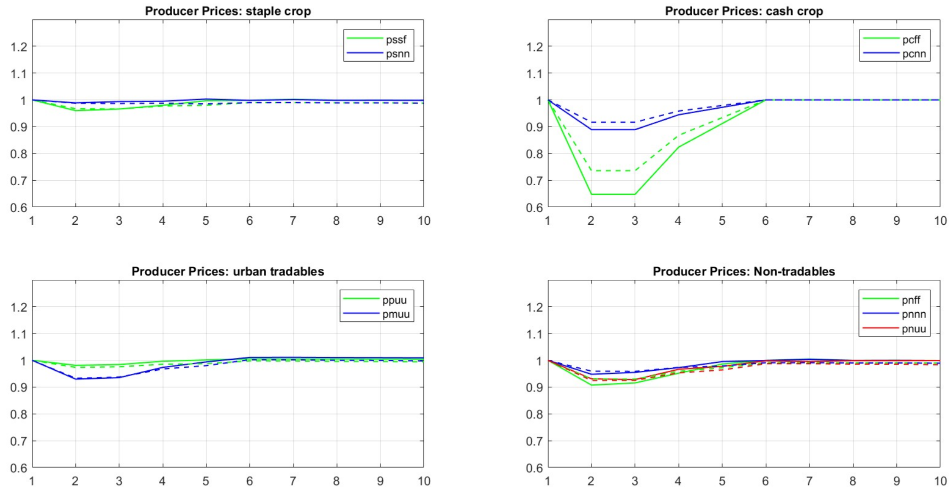
Source: Simulation 012as vs 001a. Solid lines denote path without mitigation while dashed lines indicate path with mitigation. Legend notation: labels consist of three indicators. The first letter, q, l, w, b, r denotes production, employment, wages, land rents and returns on capital, repsectively; the second, s, c, p, m, and n denotes staple foods, cash crops, processed food, manufactures and non-traded good and services respectively; while the final letter f, n, and u denote far, near and urban locations.

These relatively modest differences in the impact on aggregate output have significant implications for the public finance of the two mitigation strategies (see Figure 16), operating through the impact on the tax base of the two fiscal response strategies. As noted above, the subsidy policy more effectively mitigates both the reduction in domestic production of tradable goods in response to the external price shock and the consequent returns to domestic factors of production in both the rural and urban economy. Moreover, and for the same reasons, a subsidy-based policy response limits the extent of 'localization' thereby better protecting rents earned from the transportation of goods. Taken together, these factors limit the contraction in the domestic tax base relative to the case where mitigation is via (un-taxed) household transfers, particularly that part of the base owned by the capitalist household. The direct consequence is that the latter transfer policy requires a significantly larger and more persistent increase in the tax rate on the capitalist household, even though the direct cost of the policy intervention is common across the two strategies. In particular, given the relatively narrow tax base of the capitalist household, the tax rate rises by almost twice as much under transfers (by 17 percentage points over the baseline at the maximum) as under subsidies, an increase that would be politically infeasible in most circumstances. On this criterion alone, and for the fiscal structure represented in the baseline calibration, heavy reliance on mitigation via pure income transfers may simply be infeasible.

Figure 16 and the final three panels of Table 5 examine how household consumption and welfare outcome differ between the two strategies. The most striking feature from the top

small size of these sectors; See Table 2.

Figure 13: Partial subsidy increase: producer prices by product and location



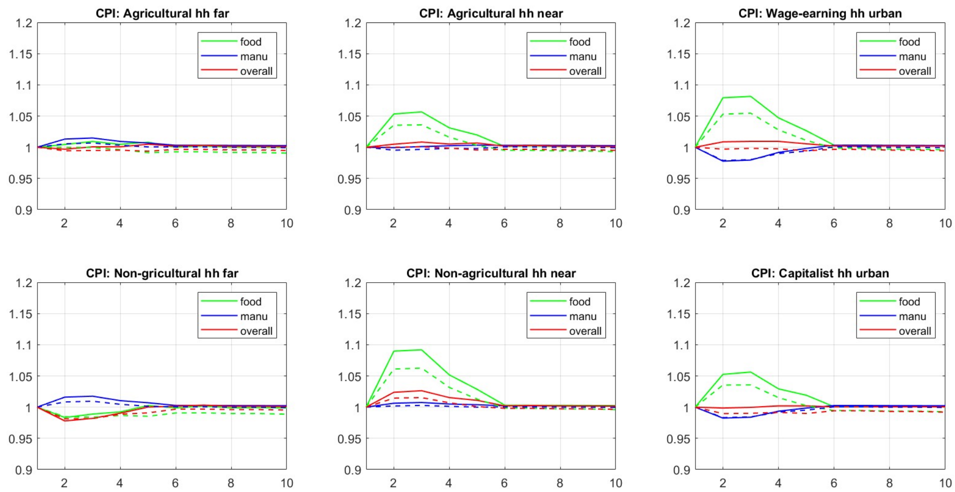
Source: Simulation 012as vs 001a. Solid lines denote path without mitigation while dashed lines indicate path with mitigation. Legend notation: labels consist of three indicators. The first letter, q, l, w, b, r denotes production, employment, wages, land rents and returns on capital, repsectively; the second, s, c, p, m, and n denotes staple foods, cash crops, processed food, manufactures and non-traded good and services respectively; while the final letter f, n, and u denote far, near and urban locations.

row of Figure 16 is that consumption paths are markedly smoother when mitigation is by way of subsidies compared to transfers and this is true both for those households that are credit-rationed and those that are not. The principal reason is that subsidies lean against both the income effect of the price shock, as do transfers, but also partially insulate household from the substitution effects of the price shock. As panel (b) points out, this smoothing effect carries over so that cumulative per capita consumption is better protected under a program of subsidies both in aggregate and for all the non-capitalist households than under one of transfers. This is not the case for the capitalist household, however, at least for the parameterization presented here. Under transfers, consumption is more volatile, dropping sharply in the first period post-shock but recovering more rapidly thereafter. This more rapid recovery reflects developments in the bond market where the sharp rise in (un-taxed) income earned from bonds as interest rates and government borrowing rise sharply over the initial period. As (sticky) taxes rise and interest rates fall in the transfer case relative to the subsidies case, the consumption paths re-cross.[29]

We can take this analysis one step further by examining the welfare differences between the two policy interventions. Panel (c) of Table 5 reports welfare calculations for each household based on equation (23). Panel (d) reports summary measures for the economy as a whole using a social welfare measure that is sensitive to distributional considerations (see Buffie

[29]Note that as calibrated, the inter-temporal elasticity of substitution is assumed to be relatively low, toward the low end of the estimates reported by Kimball et al. (2024) so that interest rates are rather more volatile and consumption smoothing less than would occur if we assumed inter-temporal substitutability were larger.

Figure 14: Partial subsidy increase: consumer price indices by household type



Source: Simulation 012as vs 001a. Solid lines denote path without mitigation while dashed lines indicate path with mitigation. Legend notation: labels consist of three indicators. The first letter, q, l, w, b, r denotes production, employment, wages, land rents and returns on capital, repsectively; the second, s, c, p, m, and n denotes staple foods, cash crops, processed food, manufactures and non-traded good and services respectively; while the final letter f, n, and u denote far, near and urban locations.

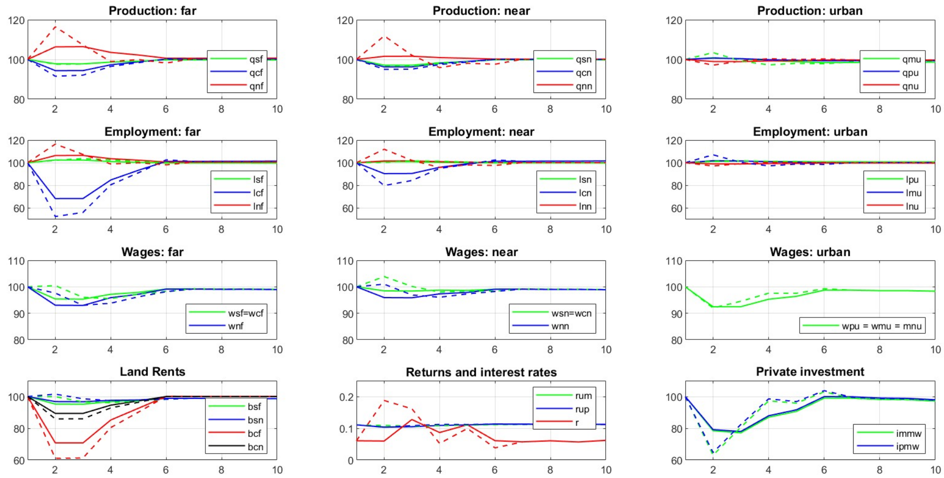
et al. (2024)). In this set-up, explicit concerns about the lower-end of the income distribution are incorporated by modifying the utility function (23) as

$$U(\zeta) = \sum_{t=0}^{\infty} \beta^t \frac{(\bar{c}_t + \zeta \bar{c}_t^j)^{(1-1/\tau)}}{1 - 1/\tau},$$

where $\bar{c}_t$ is average per capita consumption, and $\bar{c}_t^j$ is the average of the 'preferred group', j. In the case reported in panel (d), the preferred group are rural households, and ζ is a measure of the relative welfare weight placed on the preferred group. Note that $1 + \zeta$ is the marginal rate of substitution in social welfare between the consumption of the preferred and the non-preferred group in social welfare: the higher is ζ, the more weight is placed on the welfare of the preferred group. The results reported in panel (d) are for $\zeta = 0, 1$, and 2. Note that when $\zeta = 0$ the measure collapses to the simple aggregate as defined by equation (23) and is indifferent to the between-group distribution of income.

Table 5, panel (d) reports the 'welfare premium' associated with a subsidy-based rather than a transfer-base mitigation strategy. The $\zeta = 0$ measure implies that on the basis of a simple utilitarian approach – where households are weighted by the relative size of households – social welfare is higher when mitigation is based on subsidies as opposed to transfers, other things equal. But when the welfare of rural households features in social welfare (i.e. when $\zeta > 0$) social welfare is higher under a 'transfers' policy, reflecting in particular the welfare gains of the 'near households' and the non-agricultural household in the far region.

Figure 15: Subsidies vs Transfer: production, employment and wages



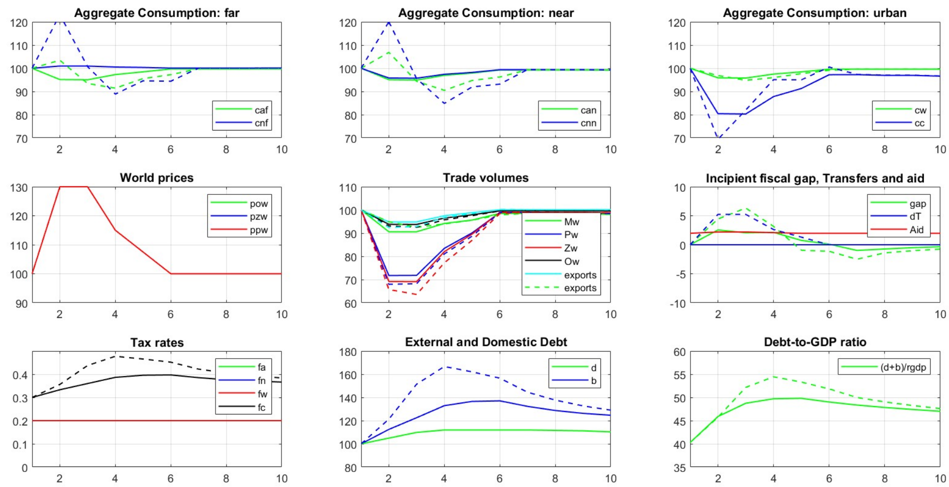
Source: Simulation 013as vs 012as. Solid line denotes subsidies, dashed line transfers. Legend notation: labels consist of three indicators. The first letter, q, l, w, b, r denotes production, employment, wages, land rents and returns on capital, repsectively; the second, s, c, p, m, and n denotes staple foods, cash crops, processed food, manufactures and non-traded good and services respectively; while the final letter f, n, and u denote far, near and urban locations.

6 Conclusion

In recent years, policymakers have been increasingly concerned about the consequences for producers and consumers in low-income countries of price shocks originating from elsewhere in the global economy. The impact of these shocks is not uniform, either across or within countries, but rather reflects structural and spatial patterns of production and consumption. The more pronounced are these spatial differences – for example in poverty, employment, or food security – the more important it becomes to understand both the spatial dimension of external shocks and how otherwise equivalent policy responses mitigate or amplify these impacts. In this paper we have developed an operational dynamic spatial general equilibrium model of an archetype small open agricultural economy in order to study these heterogeneous effects.

Motivated by the consequences for global commodity prices of Russia's invasion of Ukraine in early 2022, we use our model to illustrate the spatial impact of a temporary shock to multiple prices – in particular, of food, fertilizer and fuel – on spatial patterns of production, consumption and prices for Tanzania. In particular, we show how by exacerbating transport cost frictions in the spatial economy, the price shock promotes increased localization or disintegration of economic activity by both leveraging the scale of adverse goods price shocks in distant locations and simultaneously shifting demand in favor of local goods and non-tradable services. We then use the model to contrast two potential policy responses. In doing so, we highlight that while a policy response designed to partially offset the temporary relative price changes better protects output and aggregate consumption and promotes a more rapid recov-

Figure 16: Subsidies vs Transfer: consumption, trade and fiscal balance



Source: Simulation 013as vs 012as. Solid line denotes subsidies, dashed line transfers. Legend notation: labels consist of three indicators. The first letter, q, l, w, b, r denotes production, employment, wages, land rents and returns on capital, repsectively; the second, s, c, p, m, and n denotes staple foods, cash crops, processed food, manufactures and non-traded good and services respectively; while the final letter f, n, and u denote far, near and urban locations.

ery post-shock, a policy based on protecting household incomes through household transfers may be more favorable if the welfare of rural households is prioritized.

It is, of course, important to acknowledge that these conclusions concerning the effects of alternative fiscal interventions assume both are implemented in a targeted, credible and time-consistent manner. To the extent that these favorable conditions do not prevail, for example if either subsidies or transfers are not credibly temporary (i.e. they prove difficult to reverse once the price shock passes) or cannot be correctly targeted to specific household types. Such fiscal management challenges necessarily drive a wedge between our simulation results and the feasible set of options facing policymakers.

The model structure and the simulations presented here have been designed as a 'proof of concept' structure and calibrated to a very specific context and set of experiments. However, the underlying model structure is very flexible, and it is straightforward and relatively simple to modify the model to reflect a host of differential structural characteristics and settings that may be prevalent in other low-income countries, where spatial patterns of production and settlement may differ. Four main areas of model modification and development suggest themselves for further work. First, the model can be adjusted in terms of the spatial disaggregation of production and consumption, including assumptions on the ease with which domestic factors of production are mobile either inter-sectorally and/or across locations.[30] An important element of this work would be to allow for internal labor migration, not just

[30] As noted above, the transport sector is modeled in a very simple fashion. It is a relatively straightforward step to provide for an explicit treatment of the transport services sector in a manner that allows for sector-specific public policy to be considered.

between sectors within regions but also between regions. Second, the specific form of price determination – in other words, which goods and services are internally or externally tradable or non-tradable – can readily be altered. Third, further work could be undertaken to integrate more fully articulated fiscal structures in the model. At present, revenue is generated from tariffs and simple taxes on factor incomes. The model could instead provide for differentiated taxation of labor by location and for similarly differentiated domestic consumption taxation. Another modification might be to consider government expenditure on public infrastructure; the current version has the government spending only on transfers and debt service, but this restriction could easily be relaxed. Fourth and finally, alternative dynamic closure assumptions can be considered.

In spite of these limitations, the model offers valuable insights into the ways in which we can understand the differentiated impacts of both price shocks and policy responses on an economy that is characterized by variations in exposure to international markets. In particular, this structure allows us to see how an economy that is open at the border (and perhaps in a coastal urban area and its most closely connected interior locations) may be vulnerable to shocks that do not pass through very clearly into more remote locations. Since this description arguably characterizes many sub-Saharan economies, the relevance of this model structure is clear. Further work within the same analytic framework should provide useful insights to other country cases and contexts.

Table 5: Transfers vs Subsidies: Comparative Performance

(a) 5-year cumulative output difference [1]

		Sector								
	Agg.		Far			Near			Urban	
	Output	**Staple**	**Cash**	**NT**	**Staple**	**Cash**	**NT**	**Food**	**Manuf**	**NT**
Subsidies	-3.67	-6.89	-15.07	19.15	-8.75	-10.49	4.86	-0.21	-2.27	-3.83
Transfers	-4.15	-7.14	-21.26	20.71	-9.88	-13.77	5.53	-0.31	-4.17	-3.08
Diff[% points] [2]	0.48	0.25	6.19	-1.56	1.13	3.28	-0.67	0.10	1.90	-0.75

Notes: [1] Cumulative percentage difference in real output under world price shock and relevant mitigation strategy relative to no-shock baseline; aggregate output computed at baseline relative prices. [2] A positive difference, in percentage points, implies output is higher (or less negative) under a subsidy-based mitigation strategy compared to a transfers-based strategy. Subsidies from simulation TzaD_run_12a_slowtax.mat and transfers from simulation TzaD_run_13a_slowtax.mat

(b) 5-year cumulative per capita consumption difference [1]

		Household					
	Agg.	**Far**		**Near**		**Urban**	
	Consum.	**Ag**	**Non-Ag**	**Ag**	**Non-Ag**	**Worker**	**Capitalist**
Subsidies	-26.44	-14.41	2.90	-15.93	-13.48	-12.80	-32.98
Transfers	-27.28	-18.87	1.70	-17.29	-14.44	-15.50	-27.98
Diff [% points] [2]	0.85	4.46	1.19	1.37	0.96	2.70	-4.99

Notes: [1] Cumulative percentage difference in real per capita consumption by household type under world price shock and relevant mitigation strategy relative to no-shock baseline; aggregate output computed at baseline relative prices. [2] A positive difference, in percentage points, implies output is higher (or less negative) under a subsidy-based mitigation strategy compared to a transfers-based strategy. Subsidies from simulation TzaD_run_12a_slowtax.mat and transfers from simulation TzaD_run_13a_slowtax.mat

(c) Household Welfare Comparisons [1]

		Household					
	Agg.	**Far**		**Near**		**Urban**	
	Consum.	**Ag**	**Non-Ag**	**Ag**	**Non-Ag**	**Worker**	**Capitalist**
Subsidies	251.84	173.89	166.46	190.84	158.82	265.16	477.22
Transfers	251.83	173.80	166.46	190.86	158.85	265.07	477.38
Difference [2]	0.01	0.09	0.00	-0.02	-0.03	0.09	-0.16

Note: [1] Welfare measured on basis of household-specific utility function with inter-temporal elasticity of substitution $\tau = 1.5$ and $\beta = 1/(1+r) = 0.9428$. [2] A positive difference implies welfare is higher under a subsidy-based mitigation strategy compared to a transfers-based strategy. Subsidies from simulation TzaD_run_12a_slowtax.mat and transfers from simulation TzaD_run_13a_slowtax.mat

(d) Social Welfare Comparisons [1]

	Welfare Weights (Buffie et al)		
	0	**1**	**2**
Difference [2]	0.818	-0.621	-0.811

Note: [1] See text for definition of Social Welfare functions. [2] A positive difference implies welfare is higher under a subsidy-based mitigation strategy compared to a transfers-based strategy. Subsidies from simulation TzaD_run_12a_slowtax.mat and transfers from simulation TzaD_run_13a_slowtax.mat

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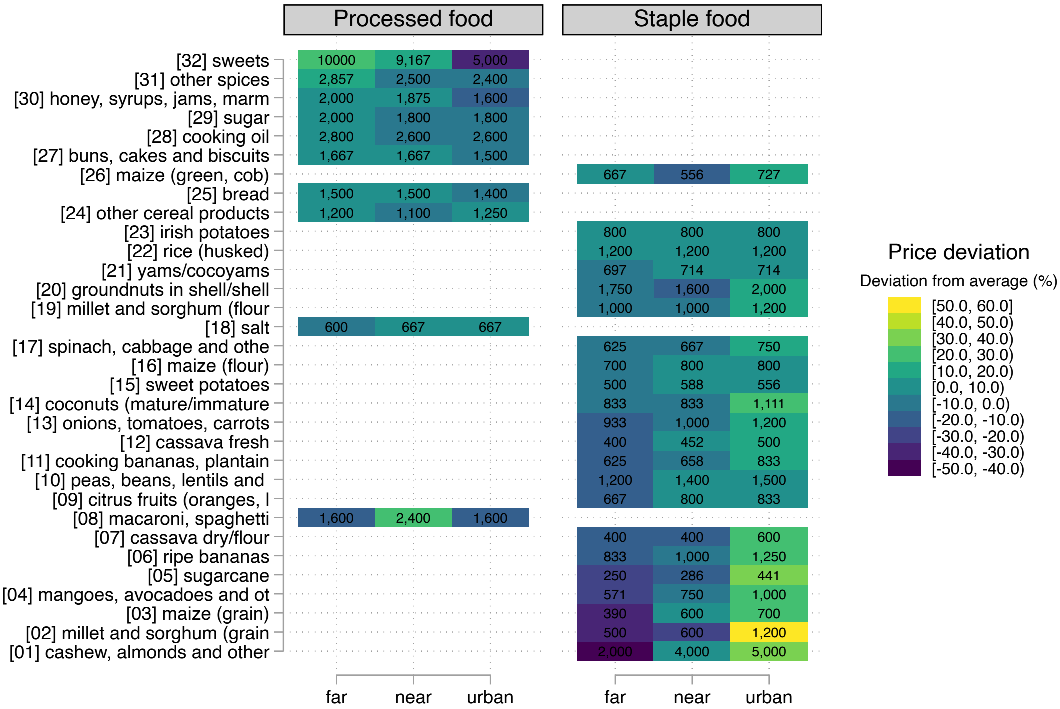
A Additional figures

A.1 Spatial heterogeneity in food prices

Figure A1: Regional differences in consumer prices of food items (LSMS 2010-11)



Note: This figure shows median prices of different food items in far rural, near rural, and urban regions. Prices are calculated from households' expenditure and consumption quantities. Values reported in this figure are median prices in each of the regions, shown as Tanzanian shilling per kilogram/liter. The color scale indicates whether a given regional price is high or low compared to the other regions. The color shading codes a given price's deviation from the mean across all three regions; e.g. for [01] cashew, almonds and other nuts, the price in far rural was 2,000 tsh/kg, which was 45% lower than the average across the three regions (2,000+4,000+5,000)/3=3,666. Source: LSMS, National Panel Survey (wave 2, 2010-11), food consumption questionnaires.

B Model appendix

This Appendix outlines the principal equations of the model. MATLAB codes for the full model, including all relevant price definitions and constraints are available upon request to the corresponding author. Unless required, we suppress time subscripts in this presentation.

B.1 Production

B.1.1 Agriculture

Agricultural production in the rural regions is modeled using a nested CES production function, with labor (L) and fertilizer (Z) on the lower tier, and the resulting composite combined with fixed endowments of land (A) on the upper tier:

$$Q_i = a_i \left[\lambda_i^{\frac{1}{\gamma_i}} A_i^{\frac{\gamma_i - 1}{\gamma_i}} + (1-\lambda_i)^{\frac{1}{\gamma_i}} \left(\delta_i^{\frac{1}{\theta_i}} L_i^{\frac{\theta_i - 1}{\theta_i}} + (1-\delta_i)^{\frac{1}{\theta_i}} Z_i^{\frac{\theta_i - 1}{\theta_i}} \right)^{\frac{\theta_i(\gamma_i - 1)}{(\theta_i - 1)\gamma_i}} \right]^{\frac{\gamma_i}{\gamma_i - 1}} \tag{1}$$

where $i = \{Sf, Sn, Cf, Cn\}$ denotes the type of crop (staple, cash) and and $l = \{f, n\}$ denotes location (far, near). The parameters γ_i and θ_i are elasticities of substitution and λ_i and δ_i are share parameters in the upper and lower level CES functions respectively, and a_i is a crop- and region-specific productivity parameter.

The representative farmer's problem for for crop i in location l is given by:

$$\max_{L_i, Z_i} p_i^l Q_i - b_i A_i - w_l L_i - p_Z^l Z_i,$$

where the rental cost of land is denoted by b_i, w_l is the wage paid to labor, and p_Z^l is the price of fertilizer in location l. The corresponding first order conditions for labor L_i, fertilizer, Z_i and for the rental rate, b_i are:

$$\begin{aligned} \frac{\partial}{\partial L_i} =& p_i^l Q_i^{\frac{1}{\gamma_i}} (1-\lambda_i)^{\frac{1}{\gamma_i}} \left(\delta_i^{\frac{1}{\theta_i}} L_i^{\frac{\theta_i - 1}{\theta_i}} + (1-\delta_i)^{\frac{1}{\theta_i}} Z_i^{\frac{\theta_i - 1}{\theta_i}} \right)^{\frac{\theta_i(\gamma_i - 1) - \gamma_i(\theta_i - 1)}{\gamma_i(\theta_i - 1)}} \\ & \left(\frac{\delta_i}{L_i} \right)^{\frac{1}{\theta_i}} - w_i \end{aligned} \tag{2}$$

$$\begin{aligned} \frac{\partial}{\partial Z_i} =& p_i^l Q_i^{\frac{1}{\gamma_i}} (1-\lambda_i)^{\frac{1}{\gamma_i}} \left(\delta_i^{\frac{1}{\theta_i}} L_i^{\frac{\theta_i - 1}{\theta_i}} + (1-\delta_i)^{\frac{1}{\theta_i}} Z_i^{\frac{\theta_i - 1}{\theta_i}} \right)^{\frac{\theta_i(\gamma_i - 1) - \gamma_i(\theta_i - 1)}{\gamma_i(\theta_i - 1)}} \\ & \left(\frac{\delta_i}{Z_i} \right)^{\frac{1}{\theta_i}} - p_Z^l \end{aligned} \tag{3}$$

$$\frac{\partial}{\partial A_i} = p_i^l Q_i^{\frac{1}{\gamma_i}} \left(\frac{\lambda_i}{A_i} \right)^{\frac{1}{\gamma_i}} - b_i \tag{4}$$

B.1.2 Manufacturing

Production in the manufacturing sector in the urban region (Mu) occurs under Cobb-Douglas conditions with labor (L) and capital (K) as inputs:

$$Q_{Mu} = a_{Mu} \, L_{Mu}^{\alpha_{Mu}} \, K_{Mu}^{(1-\alpha_{Mu})}, \tag{5}$$

where α_{Mu} is the output elasticity of labor and a_{Mu} is a sector-specific productivity parameter. The representative firm maximises profits by choosing the quantities of labor (L) and capital (K):

$$\max_{L_{Mu}, K_{Mu}} p_{Mu}^{u} \, Q_{Mu} - w_u \, L_{Mu} - r_u \, K_{Mu},$$

where w_u is the wage paid to labor in the urban region and r_u is the rental rate of capital in the urban region. The first order conditions are:

$$\frac{\partial}{\partial L_M} = \omega \, p_M^u \, a_M \left(\frac{L_M}{K_M}\right)^{\omega-1} - w_M \tag{6}$$

$$\frac{\partial}{\partial K_M} = (1-\omega) \, p_M^u \, a_M \left(\frac{L_M}{K_M}\right)^{\omega} - r_M \tag{7}$$

B.1.3 Food processing

Domestic food processing, which takes place in the urban location, (Pu), is modeled using a Leontief specification with composite staple crop ($\bar{S}$) and composite manufactures ($\bar{M}$) as intermediate inputs, and labor (L) and capital (K) as primary factors of production. The composite staple food intermediate ($\bar{S}_P$) is then a CES aggregate of the staple crop produced in the far rural region (Sf) and the staple crop produced in the near rural region (Sn):

$$\bar{S}_P = \left[\iota_S^{1/\rho_S} \, Sf_P^{(\rho_S-1)/\rho_S} + (1-\iota_S)^{1/\rho_S} \, Sn_P^{(\rho_S-1)/\rho_S} \right]^{\rho_S/(\rho_S-1)} \tag{8}$$

Similarly, the composite manufactured good used in food processing ($\bar{M}_P$) is a CES aggregate of manufactures produced domestically in the urban region (Mu) and manufactures imported from the rest of the world (Mw):

$$\bar{M}_P = \left[\iota_M^{1/\rho_M} \, Mu_P^{(\rho_M-1)/\rho_M} + (1-\iota_M)^{1/\rho_M} \, Mw_P^{(\rho_M-1)/\rho_M} \right]^{\rho_M/(\rho_M-1)} \tag{9}$$

Total intermediate input use in the urban food processing sector (Pu) is thus:

$$IN_P = (\phi_{\bar{S}P} + \phi_{\bar{M}P}) Q_{Pu}, \tag{10}$$

with $\phi_{\bar{S}P}$ and $\phi_{\bar{M}P}$ denoting the fixed input requirement of (composite) staple crop and (composite) manufactures per unit of output of processed food (Pu).

Gross output of the food processing sector (Q_{Pu}) is produced by combining value added and intermediate goods. The value of output is given by:

$$p^u_{Pu}\, Q_{Pu} = p^{va}_{Pu}\, a_{Pu}\, K^{\alpha_{Pu}}_{Pu}\, L^{(1-\alpha_{Pu})}_{Pu} + \left(p^u_{\bar{S}}\, \phi_{\bar{S}P} + p^u_{\bar{M}}\, \phi_{\bar{M}P}\right) Q_{Pu}, \tag{11}$$

where p^u_{Pu} is the gross factory-gate output price for processed food in the urban region, p^{va} the price of value added and $p^u_{\bar{S}}$ and $p^u_{\bar{M}}$ are the tariff, tax and transport cost inclusive price of the composite staple crop and the manufactured good, respectively, in the urban region.

The representative firm maximises profits by choosing the quantities of labor (L) and capital (K)

$$\max_{L_{Pu}, K_{Pu}} p^u_{Pu}\, Q_{Pu} - w_u\, L_{Pu} - r_u\, K_{Pu} - \left(p^u_{\bar{S}}\, \phi_{\bar{S}P} + p^u_{\bar{M}}\, \phi_{\bar{M}P}\right) Q_{Pu}$$

Since the optimal volume of intermediates is defined from the Leontief relation, the firm's first order conditions are defined in a conventional manner over labor (L) and capital (K) as

$$\frac{(1-\alpha)\, p^{va}_P\, va_P}{L_P} = w_P \tag{12}$$

$$\frac{\alpha\, p^{va}_P\, va_P}{K_P} = r_P \tag{13}$$

where w_P is the wage and r_P the rental rate of capital in the food processing sector.

B.1.4 Non-tradable services

In each of the three regions there exists a sector that produces local non-tradable services (N). The production of these non-tradable services is linear in labor, the single factor of production[31]

$$Q_{Nl} = a_{Nl}\, L_{Nl} \tag{14}$$

where $l = \{f, n, u\}$ denotes the region (far rural, near rural and urban) and a_{Nl} is a sector- and region-specific productivity parameter. The representative firm in region l maximizes profits by choosing the quantity of labor (L)

$$\max_{L_{Nl}} p^l_{Nl} - w_l\, L_{Nl}$$

with first order conditions

[31] At present we assume output is linear in labor; it would be trivial to allow for diminishing returns to labor.

$$\frac{p_{Nl}^l\, Q_{Nl}}{L_{Nl}} = w_l \tag{15}$$

B.2 Household income, consumption and saving

B.2.1 Budget constraints

Budget constraints for the five non-capitalist households are broadly similar. For staple crops $j = s$ and cash crops $j = c$, and locations $l = f, n$, agricultural households in far (Af) and near (An) earn income from employment ($w_{jl}\, L_{jl}$) and their ownership of land ($b_{jl}\, A_{jl}$). Factor incomes are taxed at rate f_A. These households also receive cash transfers in the amount ($\mu_T^{Af}\, T$). As hand-to-mouth consumers, this defines total consumption over goods i, with location specific prices p_i^l:

$$\sum_i \left[p_i^f\, c_i^{Af}\right] = (1 - f_A) \sum_j \left[w_{jf}\, L_{jf} + b_{jf}\, A_{jf}\right] + \mu_T^{Af}\, T \tag{16}$$

and

$$\sum_i \left[p_i^n\, c_i^{An}\right] = (1 - f_A) \sum_j \left[w_{jn}\, L_{jn} + b_{jn}\, A_{jn}\right] + \mu_T^{An}\, T. \tag{17}$$

Non-agricultural household in the rural regions, (Nf and Nn), are dependent solely on (net of tax) employment income and cash transfers from government. Consumption for these households is thus:

$$\sum_i \left[p_i^f c_i^{Nf}\right] = (1 - f_N)\left[w_{Nf}\, L_{Nf}\right] + \mu_T^{Nf}\, T \tag{18}$$

and

$$\sum_i \left[p_i^n c_i^{Nn}\right] = (1 - f_N)\left[w_{Nn}\, L_{Nn}\right] + \mu_T^{Nn}\, T. \tag{19}$$

The final hand-to-mouth household is the wage-earning household in the urban region (W). Its only sources of income are from the sale of labor ($w_{ju}\, L_{ju}$) in the three sectors $j = \{P, M, N\}$ which is taxed at rate f_W, plus a share of total transfers ($\mu_T^W\, T$). This household's consumption is give by:

$$\sum_i \left[p_i^u c_i^W\right] = \Big(1 - f_W\Big) \sum_j \left[w_{ju}\, L_{ju}\right] + \mu_T^W\, T. \tag{20}$$

The capitalist household's income comes from three domestic sources. The first two are the gross profits from capital used in the food processing and manufacturing sectors $\{p, m\}$ and rents from its monopoly control of the transport sector.[32] Transport rents for a given trade flow are calculated as the value of the trade flow at origin, multiplied by the commodity-

[32]We do not explicitly model the production of transport services here. In principle, we could introduce a monopoly transport sector which is owned and operated under conditions of monopoly by the capitalist household, possibly with capital and labor inputs.

specific wedge parameter, (ψ_i^{rent}):

$$
\begin{aligned}
rents =& \psi_1^{rent}\Big[\sum_{Nn,An}\Big(p^u_{Pu}c^h_{Pu}+p^u_{Pw}c^h_{Pw}+p^u_{Mu}c^h_{Mu}+p^u_{Mw}c^h_{Mw}\Big)\\
&+p^n_{Sn}\big(c^W_{Sn}+c^C_{Sn}\big)+p^u_Z\big(Z_{Sn}+Z_{Cn}\big)+p^n_{Cn}Q_{Cn}\Big]\\
&+\psi_2^{rent}\Big[p^n_{Sn}\big(c^{Nf}_{Sn}+c^{Af}_{Sn}\big)+p^f_{Sf}\big(c^{Nn}_{Sf}+c^{An}_{Sf}\big)\Big]\\
&+\big(\psi_1^{rent}+\psi_2^{rent}\big)\Big[\sum_{Nf,Af}\Big(p^u_{Pu}c^h_{Pu}+p^u_{Pw}c^h_{Pw}+p^u_{Mu}c^h_{Mu}+p^u_{Mw}c^h_{Mw}\Big)\\
&+p^f_{Sf}\big(c^W_{Sf}+c^C_{Sf}\big)+p^u_Z\big(Z_{Sf}+Z_{Cf}\big)+p^f_{Cf}Q_{Cf}\Big]
\end{aligned}
\tag{21}
$$

Profits and rents are taxed at the rate f_C. The final element of domestic income is interest income from its holdings of government bonds. In addition, the capitalist household receives (or pays) remittances ($remit$) from overseas. Expenditure by the capitalist household is on consumption goods, investment in physical capital in domestic manufacturing and food processing and on the net acquisition of government bonds[33]. The capitalist's period budget constraint in each period t, is given by:

$$
\begin{aligned}
\sum_i\Big[p^u_{i,t}\,c^C_{i,t}\Big]+p^k_t\,(i^p_t+i^m_t)+p^c_t\,b_t =&\big(1-f_{C,t}\big)\Big[r^p_t\,k_{Pu,t}+r^m_t\,k_{Mu,t}+rents_t\Big]\\
&+(1+r_{t-1})\,p^c_{t-1}\,b_{t-1}+remit_t.
\end{aligned}
\tag{22}
$$

B.2.2 Inter-temporal allocations

Household utility for each household type, h, is defined by the iso-elastic utility function

$$
U_h=\sum_{t=0}^{\infty}\beta^t\frac{c_t^{h\,(1-1/\tau)}}{1-1/\tau}
\tag{23}
$$

where β is the subjective discount factor and τ the inter-temporal elasticity of substitution, which is assumed to be common across all households.

The capitalist household maximizes its inter-temporal utility, equation (23), subject to the inter-temporal budget constraint, with the resulting first order condition for aggregate consumption, the Euler equation

$$
\frac{c^C_{t+1}}{c^C_t}=\Big(\beta(1+r_t)\frac{p^c_t}{p^c_{t+1}}\Big)^{\tau}
\tag{24}
$$

where c^C_t is the capitalist household's aggregate consumption in period t.

The arbitrage conditions determining the allocation of the household's saving between in-

[33]The real value of government bonds is denoted b and are indexed by the consumer price level for the capitalist household, p^c

vestment in physical capital and accumulation of claims on government are:

$$(1+r_t)\frac{pk_t}{pk_{t+1}}(1+\nu(\frac{i^m_t}{k^m_{t-1}}-\delta)) = \frac{r^m_{t+1}}{pk_{t+1}}+(1-\delta)+\nu(\frac{i^m_{t+1}}{k^m_t}-\delta)(\frac{i^m_{t+1}}{k^m_t}+1-\delta)-\frac{\nu}{2}(\frac{i^m_{t+1}}{k^m t})^2 \quad (25)$$

and

$$(1+r_t)\frac{pk_t}{pk_{t+1}}(1+\nu(\frac{i^p_t}{k^p_{t-1}}-\delta)) = \frac{r^p_{t+1}}{pk_{t+1}}+(1-\delta)+\nu(\frac{i^p_{t+1}}{k^p_t}-\delta)(\frac{i^p_{t+1}}{k^p_t}+1-\delta)-\frac{\nu}{2}(\frac{i^p_{t+1}}{k^p t})^2 \quad (26)$$

where i^m and i^p denote investment in physical capital in the manufacturing and food processing sectors, with gross returns r^m and r^p and capital stocks k^m and k^p, defined equivalently. r is the return on government bonds, δ is the common depreciation rate for capital and ν the adjustment cost parameter. Capital is both sectors constructed exclusively from imported manufactured capital goods with price pk.

The dynamics of the capital stock in sector $j = \{M, P\}$ follows directly:

$$K_{jt} = I_{jt} + (1-\bar{\delta})\, K_{jt-1} \quad (27)$$

B.2.3 Composition of consumption

All six households, $h = \{Af, Nf, An, Nn, W, C\}$, consume staple and processed food, manufactures and their local non-tradable good. We assume that whilst incomes differ, household types all share the same elasticities of substitution between goods.

Consumption is modeled in terms of a three-level nested CES structure. Aggregate consumption is a CES aggregate of composite food ($c_{\bar{F}}$), composite manufactures ($c_{\bar{M}}$), and location-specific non-tradable services (c_{Nl})

$$c^h = \left[\eta_{\bar{F}}^{1/\epsilon}\, c^h_{\bar{F}}{}^{(\epsilon-1)/\epsilon} + \eta_{\bar{M}}^{1/\epsilon}\, c^h_{\bar{M}}{}^{(\epsilon-1)/\epsilon} + (1-\eta_{\bar{F}}-\eta_{\bar{M}})^{1/\epsilon}\, c^h_{Nl}{}^{(\epsilon-1)/\epsilon}\right]^{\epsilon/(\epsilon-1)} \quad (28)$$

where ϵ is the elasticity of substitution and $\eta_{\bar{F}}$ and $\eta_{\bar{M}}$ are share parameters.

Composite food ($c_{\bar{F}}$) is a combination of the staple food ($c_{\bar{S}}$) and a composite processed food ($c_{\bar{P}}$):

$$c^h_{\bar{F}} = \left[\eta_{\bar{S}}^{1/\xi}\, (c^h_{\bar{S}} - \bar{c}_{\bar{S}})^{(\xi-1)/\xi} + (1-\eta_{\bar{S}})^{1/\xi}\, (c^h_{\bar{P}} - \bar{c}_{\bar{P}})^{(\xi-1)/\xi}\right]^{\xi/(\xi-1)} \quad (29)$$

where ξ is the elasticity parameter, $\eta_{\bar{S}}$ is the share parameter, and $\bar{c}_{\bar{S}}$ and $\bar{c}_{\bar{F}}$ are subsistence parameters that generate non-homotheticicities in consumption.

Finally, we add another layer to reflect the substitution between staple food produced in the far region and the near region on the one hand, and imported and domestically processed food on the other hand:

$$c^h_{\bar{S}} = \left[\nu_S^{1/\zeta_S}\, c^h_{Sf}{}^{(\zeta_S-1)/\zeta_S} + (1-\nu_S)^{1/\zeta_S}\, c^h_{Sn}{}^{(\zeta_S-1)/\zeta_S}\right]^{\zeta_S/(\zeta_S-1)} \quad (30)$$

where ζ_S is the elasticity parameter and ν_S is the share parameter and

$$c^h_{\bar{P}} = \left[\nu_P^{1/\zeta_P}\, {c^h_{Pu}}^{(\zeta_P-1)/\zeta_P} + (1-\nu_P)^{1/\zeta_P}\, {c^h_{Pw}}^{(\zeta_P-1)/\zeta_P}\right]^{\zeta_P/(\zeta_P-1)} \tag{31}$$

where ζ_P is the elasticity parameter and ν_P is the share parameter, respectively.

Composite manufactures ($c_{\bar{M}}$) are a combination of manufactures produced domestically in the urban region (c_{Mu}) and imported manufactures (c_{Mw})

$$c^h_{\bar{M}} = \left[\nu_M^{1/\zeta_M}\, {c^h_{Mu}}^{(\zeta_M-1)/\zeta_M} + (1-\nu_M)^{1/\zeta_M}\, {c^h_{Mw}}^{(\zeta_M-1)/\zeta_M}\right]^{\zeta_M/(\zeta_M-1)} \tag{32}$$

where ζ_M is the elasticity parameter and ν_M is the share parameter.

B.3 Market-clearing conditions

B.3.1 Commodity balances: non-tradable goods and services

The staple food crop is produced in both rural regions but is not traded internationally. It is used as an intermediate input in food processing in the urban region and for final consumption in all of the three domestic regions.

$$Q_{Sf} = \sum_h c^h_{Sf} + Sf_P \tag{33}$$

$$Q_{Sn} = \sum_h c^h_{Sn} + Sn_P \tag{34}$$

for $h = \{Af, Nf, An, Nn, W, C\}$. The markets for non-tradable services clear in each region $l = \{f, n, u\}$

$$Q_{Nl} = \sum_h c^h_{Nl} \tag{35}$$

B.3.2 Commodity balances: tradable goods

The tradable goods in the economy consist of three groups. The first is cash crops which are produced in both rural regions and are entirely exported to the rest of the world:

$$Q_{Cf} = X_{Cf} \tag{36}$$

$$Q_{Cn} = X_{Cn} \tag{37}$$

The second group are non-competitive imports, namely fuel and fertilizer. Fertilizer is used in the production of both agricultural crops (staple, cash) in both rural regions (far, near)

$$D_Z = \sum_j Z_j \tag{38}$$

where $j = \{Sf, Cf, Sn, Cn\}$. Fuel imports are determined on the same basis as transport rents:

$$\begin{aligned} fuel =& \vartheta_1 \Big[\sum_{Nn,An} \left(c^h_{Pu} + c^h_{Pw} + c^h_{Mu} + c^h_{Mw} \right) + c^W_{Sn} + c^C_{Sn} + Z_{Sn} + Z_{Cn} + Q_{Cn} \Big] \\ &+ \vartheta_2 \Big[c^{Nf}_{Sn} + c^{Af}_{Sn} + c^{Nn}_{Sf} + c^{An}_{Sf} \Big] \\ &+ (\vartheta_1 + \vartheta_2) \Big[\sum_{Nf,Af} \left(c^h_{Pu} + c^h_{Pw} + c^h_{Mu} + c^h_{Mw} \right) + c^W_{Sf} + c^C_{Sf} \\ &+ Z_{Sf} + Z_{Cf} + Q_{Cf} \Big] \end{aligned} \tag{39}$$

where ϑ_1 denotes the per-unit fuel requirement to transport goods from the urban to the near region and ϑ_2 the corresponding requirement to move goods between near and far rural regions.

Finally, we have processed food and manufactured goods which are produced in the urban region and consumed domestically, in all three regions, but which compete against import varieties, denoted D_{Pw} and D_{Mw}. The commodity balance for processed food is

$$Q_{Pu} + D_{Pw} = \sum_h \left(c^h_{Pu} + c^h_{pw} \right) \tag{40}$$

for $h = \{Af, Nf, An, Nn, W, C\}$.

Likewise, manufactures are consumed in each of the three domestic regions but are also used as intermediate inputs in the production of processed food, and used in the production of capital.

$$Q_{Mu} + D_{Mw} = \sum_h \left(c^h_{Mu} + c^h_{Mw} \right) + Mu_P + Mw_P + I_M + I_P \tag{41}$$

for households h as above.

B.3.3 Factor market clearing

Land is fixed both in aggregate supply and between cash crops and staples across the two rural regions.

Labor markets are integrated within region, resulting in three separate markets in the economy. Within a given labor market, labor moves frictionlessly between sectors. Thus in the rural areas:

$$\bar{L}_f = L_{Sf} + L_{Cf} + L_{Nf} \tag{42}$$

and

$$\bar{L}_n = L_{Sn} + L_{Cn} + L_{Nn} \tag{43}$$

In the urban region (u), labor can be allocated to food processing (P), manufacturing (M), or the non-tradable services sector (N)

$$\bar{L}_u = L_{Pu} + L_{Mu} + L_{Nu} \tag{44}$$

Finally, capital is only used in production processes in the urban region and can be allocated to the food processing or the manufacturing sector

$$\bar{K} = K_P + K_M \tag{45}$$

Capital is produced exclusively from imported manufactured goods (Mw).

B.4 Fiscal Balance, Fiscal Rules and the Current account

External balance is defined as

$$\begin{aligned} p_{Cw}\left(Q_{Cf} + Q_{Cn}\right) + Aid + R + \Delta D_c + NR = & \, p_{Mw}\left(\sum_h c^h_{Mw} + Mw_P\right) + p_{Pw}\left(\sum_h c^h_{Pw}\right) \\ & + p_{Zw}\left(\sum_i Z_i\right) + p_{Ow}\, fuel \\ & + p_K\left(I_{Pu} + I_{Mu}\right) + r^d D_c \end{aligned} \tag{46}$$

where Aid denotes official aid transfers, D_c the stock of concessional official debt (where Δ is the difference operator), r^d the interest rate on concessional debts, R net remittance inflows to the capitalist household, and NR is the exogenous net exports from the (un-modeled) natural resource sector.

The fiscal balance is defined as:

$$\begin{aligned} r^d D_C + r\, P_C\, B + s_Z\, E\, p_{Zw}\, D_Z + s_O\, E\, p_{Ow}\, fuel + T = & \, Aid + f_A \sum_i \left(w_i\, L_i + b_i\, A_i\right) \\ & + f_N \sum_j \left(w_j\, L_j\right) + f_W \sum_k \left(w_k\, L_k\right) \\ & + f_C\Big(p_K\, r_u\, (K_{Pu} + K_{Mu}) + rents\Big) \\ & + t_M\, E\, p_{Mw}\, D_M + t_P\, E\, p_{Pw}\, D_P \\ & + t_C\, E\, p_{Cw}\left(Q_{Cf} + Q_{Cn}\right) + \Delta D_c + \Delta B \end{aligned} \tag{47}$$

The final element of the model are a set of fiscal rules which define how fiscal balance is restored following any given shock and/or purposive fiscal policy adjustment. We first define *gap* as the incipient fiscal balance given the exogenously determined levels of aid and concessional borrowing, at the prevailing tax rates, transfers and domestic borrowing. At the initial equilibrium, $gap = 0$, but changes to the tax base – in response to external price shocks – and/or changes in subsidy and tariff rates, generate a non-zero incipient fiscal gap which must be closed by adjustment to tax and transfer rates. The target adjustment of each tax rate is defined by the following dynamic rules:

$$f_A^* = f_{A,t} + \lambda_1^A \frac{gap}{\sum_i \Big(w_i \, L_i + b_i \, A_i \Big)} \tag{48}$$

for $i = \{Sf, Sn, Cf, Cn\}$.

$$f_N^* = f_{N,t} + \lambda_1^N \frac{gap}{\sum_i \Big(w_j \, L_j \Big)} \tag{49}$$

for $j = \{Nf, Nn\}$.

$$f_W^* = f_{W,t} + \lambda_1^W \frac{gap}{\sum_k \Big(w_u \, L_k \Big)} \tag{50}$$

for $k = \{P, M, U\}$.

$$f_C^* = f_{C,t} + \lambda_1^C \frac{gap}{\Big(p_K \big(r_p K_{Pu} + r_m K_{Mu} \big) + rents \Big)} \tag{51}$$

and

$$T^* = T_{C,t} - \lambda_1^T \, gap \tag{52}$$

where the λ_1 parameters are adjustment weights and $\sum_m \lambda_1^m = 1$ for $m = A, N, W, C, T$.

These rules define the *overall* shares of fiscal adjustment borne by each fiscal instrument. However, we assume that tax and transfer adjustments are not immediate so that period-by-period adjustment is facilitated by domestic borrowing, subject to the constraint that the domestic debt stock must return eventually to its initial value, b^*. Hence, for tax instruments, m, actual fiscal adjustment follows an partial adjustment path

$$f_{m,t} = f_{m,t-1} + \lambda_2^m \Big(f_m^* - f_{m,t-1} \Big) + \lambda_3^m \Big(b_{t-1} - b^* \Big) \tag{53}$$

B.5 Domestic prices

Finally, to complete the description of the model, Table B1 defines the full array of local, market-clearing prices across the sectors and locations of the model.

Table B1: Local prices

Product	Origin		Local prices at destination			
			Far rural	Near rural	Urban	RoW
Non-tradables	Far	Nf	p^f_{Nf}	-	-	-
	Near	Nn	-	p^n_{Nn}	-	-
	Urban	Nu	-	-	p^u_{Nu}	-
Staple crop	Far	Sf	p^f_{Sf}	$p^n_{Sf} = p^f_{Sf}(1+\psi^{rent}_2) + \psi^{fuel}_2$	$p^u_{Sf} = p^f_{Sf}(\psi^{rent}_1 + \psi^{rent}_2) + \psi^{fuel}_1 + \psi^{fuel}_2$	-
	Near	Sn	$p^f_{Sn} = p^n_{Sn}(1+\psi^{rent}_2) + \psi^{fuel}_2$	p^n_{Sn}	$p^u_{Sn} = p^n_{Sn}(1+\psi^{rent}_1) + \psi^{fuel}_1$	-
Cash crop	Far	Cf	$p^f_{Cf} = \frac{Ep^w_C - \psi^{fuel}_1 - \psi^{fuel}_2}{(1+\psi^{rent}_1+\psi^{rent}_2)(1+t_C)}$	-	-	Ep^w_C
	Near	Cn	-	$p^n_{Cn} = \frac{Ep^w_C - \psi^{fuel}_1}{(1+\psi^{rent}_1)(1+t_C)}$	-	Ep^w_C
Manufactures	Urban	Mu	$p^f_{Mu} = p^u_{Mu}(\psi^{rent}_1 + \psi^{rent}_2) + \psi^{fuel}_1 + \psi^{fuel}_2$	$p^n_{Mu} = p^u_{Mu}(1+\psi^{rent}_1) + \psi^{fuel}_1$	p^u_{Mu}	-
	RoW	Mw	$p^f_{Mw} = (1+t_M)Ep^w_M(\psi^{rent}_1 + \psi^{rent}_2) + \psi^{fuel}_1 + \psi^{fuel}_2$	$p^n_{Mw} = (1+t_M)Ep^w_M(1+\psi^{rent}_1) + \psi^{fuel}_1$	$p^u_{Mw} = (1+t_M)Ep^w_M$	Ep^w_M
Processed food	Urban	Pu	$p^f_{Pu} = p^u_{Pu}(\psi^{rent}_1 + \psi^{rent}_2) + \psi^{fuel}_1 + \psi^{fuel}_2$	$p^n_{Pu} = p^u_{Pu}(1+\psi^{rent}_1) + \psi^{fuel}_1$	p^u_{Pu}	-
	RoW	Pw	$p^f_{Pw} = (1+t_P)Ep^w_P(\psi^{rent}_1 + \psi^{rent}_2) + \psi^{fuel}_1 + \psi^{fuel}_2$	$p^n_{Pw} = (1+t_P)Ep^w_P(1+\psi^{rent}_1) + \psi^{fuel}_1$	$p^u_{Pw} = (1+t_P)Ep^w_P$	Ep^w_M
Fertiliser	RoW	Z	$p^f_Z = (1+t_Z)Ep^w_Z(\psi^{rent}_1 + \psi^{rent}_2) + \psi^{fuel}_1 + \psi^{fuel}_2$	$p^n_Z = (1+t_Z)Ep^w_Z(1+\psi^{rent}_1) + \psi^{fuel}_1$	-	Ep^w_Z
Fuel	RoW	O	-	-	-	Ep^w_O

C Calibration appendix

C.1 Introduction

The basis for calibration of the model is the 2018 Social Accounting Matrix (SAM) for Tanzania compiled by IFPRI, the International Food Policy Research Institute (Thurlow, 2021). This is a *national* SAM that distinguishes 42 activities and commodities and 10 households, consisting of five rural households, ordered by income quintile, and five similarly ordered urban households. Factors of production consist of three classes of labor, differentiated by level of educational achievement; land, which is used only in agricultural production; and capital, which in employed in all sectors. The SAM is defined in value terms and traces flows of spending across the economy. Household spending on commodities accrues to producers, net of taxes, who in turn purchase intermediate inputs from other firms and the rest of the world and employ factors of production owned by households. Some share of domestic production is exported and some proportion of final expenditures on consumption goods, intermediate inputs and capital goods, is imported. A government account tracks revenue mobilization through direct, indirect and trade taxes, and spending on goods and services, debt service and on the accumulation and maintenance of infrastructure capital. Net flows of saving by households, government and the rest of the world constitute the residual vector of flows that balance the SAM for each activity and commodity, for each household, for the government account and the aggregate external balance of payments.

Transforming this SAM into a form that is consistent with the specific structure of production and consumption used in the model, including their spatial distribution, requires a set of aggregation and allocation choices. These are implemented on the basis of data from other sources and are ultimately disciplined by the constraints of our model structure and by our own judgments, subject to the objective that the overall control totals in the SAM, including for the overall level and structure of GDP, are preserved as best as possible.

C.2 Initial aggregation over commodities and households

The first step involves aggregating from the 42 SAM commodities to the six model commodities: staple food; cash crops; processed food; manufactured goods; non-tradable goods and services; and natural resources and tourism. The allocation between staples, cash crops and processed foods follows directly from Figure 6. Manufactured goods consist of all remaining tangible commodities in the SAM,[34] while the non-tradable sector is a simple aggregation of all the remaining activities in the SAM except for mining and hotels which are aggregated into the natural resources and tourism sector. This final sector, which has a high net export content, is treated in the model as an enclave sector employing no domestic factors of production and exporting its entire output: it plays no substantive role in our simulation analysis

[34] These are textiles, wood, chemicals, metal and non-metal goods, machinery and other manufactures.

but its existence helps preserve the coherence of the model with the underlying data.

This first aggregation over commodities and activities is done at the national level. Likewise, on the household side, we initially define a single rural household as the aggregate of all five rural quintiles and likewise a single urban household. Flows of labor income are aggregated accordingly by sector and household type. All land is deemed to be owned by the rural household who receive total rental incomes. Gross returns to capital accrue to a 'capitalist' household. This is not separately defined in the IFPRI SAM: we describe the construction of this household account below. Finally, at this initial stage, we make a number of further alterations and re-allocations to the SAM to map the data to our model structure. These are as follows:

- All elements in the input-output structure other than intermediate inputs of staple food and manufactured goods into processed food production are set to zero. This necessarily changes the value of gross output and gross expenditure in each sector; the row-column balance in the SAM is restored by absorbing the net expenditure by sector in the final consumption vector.
- All investment spending by sector of origin, including via change in stocks, is reallocated to the manufactured goods sector (this being the only input into investment spending in our model).
- Household-specific savings and investment spending are allocated to the capitalist household, the only non hand-to-mouth household in the model (see below).
- All exports of staples, cash crops and processed foods are allocated to cash crops (and will later be disaggregated by location). All other exports are treated as elements of the non-modeled 'natural resource and tourism' export-only sector.
- All imports of staples, cash crops and processed foods are reallocated to processed food imports. Mining and tourism imports are netted off against exports from this sector and all other imports are treated as imports of manufactures. Residual imports of labor, labor services and final direct imports by households are all set to zero.

Taken as a whole, this set of adjustments to the SAM, which are necessary to provide for a model-consistent calibration, would appear to be radical. In practice, however, with the exception of our suppression of the majority of the input-output structure, most of these changes are marginal and do not radically alter the overall structure of production and consumption. For example, it is the case that the majority of food exports are of cash crops and the majority of non-resource, non-agricultural exports are of manufactured goods. Likewise, most imports are of processed foods and manufactured goods. Similarly, we regard it as a reasonable approximation that most households in Tanzania are hand-to-mouth and do not save and investment (other than, of course, enjoying title to rural land).

C.3 Spatial distribution of activity

The preceding adjustments serve to re-shape the aggregate *national* SAM. The next step involves using geo-referenced microeconomic survey data from the World Bank's Living Standards Measurement Study (LSMS) to inform the spatial allocations of land and labor and hence of employment and consumption across locations in the economy. As noted in **??** we assume three regions: far, near and urban. Staple and cash crops are produced using land and labor in both the far and near regions while processed food and other manufactured goods are produced using capital and labor in the urban region. We assume region-specific non-tradable goods are produced using only local labor in each of the three regions. Each region is populated by two households each: in far and near these are an agricultural household and a non-agricultural household while in the urban region there is a wage-earning and a capitalist household. To effect the spatial allocation of production and consumption across these three locations, the following adjustments are made to the SAM:

- We draw on five waves of Tanzanian LSMS data from 2008-2019 (National Panel Survey data collection waves 1-4, plus the extended panel collected in 2019), to estimate the spatial distributions of land and labor across sectors. These are shown in Table C2. The same LSMS data also generates data on the average intensity of fertilizer use between staple and cash crops across regions. Land rental rates are not fully equalized across crops and locations: we assume for convenience that rental in far are similar but that rental rates are higher in near and higher for cash crops in near than staple crops.

- The model assumes that labor markets clear by location hence equalizing wages across locations. By dint of allocation of labor and production of staples, cash crops and non-tradable goods and services between far and near locations, this implies a baseline wage premium of approximately 47% accruing to those employed in the near region relative to the far region.

- The foregoing aggregations and sectoral allocation of production, trade and factors, combined with the model assumption that all the non-capitalist households consume their entire income period-by-period, the assumptions on public finance, and the treatment of transport costs, imply a residual matrix of final consumption. Relative to the SAM, our constructed capitalist household, discussed below, gives us an additional degree of freedom which allows for small re-allocations of final consumption between households to ensure the final consumption vector is consistent with evidence on household expenditures in low-income countries while respecting the balance requirements of the SAM.[35]

- Transport costs consist of two elements, the first being fuel costs and the second rents accruing to the capitalist household as the owner of the transport and distribution

[35] The final income-expenditure balance for the non-capitalist households is guaranteed by deriving net household transfers from government.

system. The IFPRI SAM includes a separate transport cost wedge. Using earlier work by two of the authors (Adam et al., 2018) and data on total fuel imports from (IMF, 2022) this transport cost wedge is partitioned into a fuel-cost component (which forms part of imports) and a rental component (accruing to the capitalist household) and allocated across final consumption and intermediate goods in terms of their location of consumption.

- The final household consumption vectors at producer and consumer prices are shown in Table C1.

Table C1: Final consumption vector

	Far Agric.	Far Non-ag.	Near Agric.	Near Non-ag.	Urban Worker	Urban Capital
Real consumption (per capita)						
Staple food – Far	0.35	0.24	0.13	0.06	0.10	1.22
Staple food – Near	0.04	0.05	0.32	0.16	0.13	0.36
Processed food – Urban	0.06	0.04	0.08	0.07	0.26	0.62
Processed food – Imports	0.05	0.04	0.09	0.07	0.28	0.66
Manufactured good – Urban	0.06	0.05	0.08	0.04	0.18	0.71
Manufactured good – Imports	0.11	0.12	0.16	0.12	0.37	2.04
Non-tradables – Far	0.06	0.13	–	–	–	–
Non-tradables – Near	–	–	0.14	0.07	–	–
Non-tradables – Urban	–	–	–	–	0.39	2.95
Consumer Prices						
Staple food – Far	1.00	1.00	1.53	1.53	2.05	2.05
Staple food – Near	1.53	1.53	1.00	1.00	1.53	1.53
Processed food – Urban	3.21	3.21	2.66	2.66	2.10	2.10
Processed food – Imports	1.81	1.81	1.46	1.46	1.10	1.10
Manufactured good – Urban	1.48	1.48	1.24	1.24	1.00	1.00
Manufactured good – Imports	1.61	1.61	1.36	1.36	1.10	1.10
Non-tradables – Far	1.00	1.00	–	–	–	–
Non-tradables – Near	–	–	1.00	1.00	–	–
Non-tradables – Urban	–	–	–	–	1.00	1.00
Consumption expenditure shares						
Staple food – Far	35%	26.5%	14.7%	11.8%	9.3%	22.7%
Staple food – Near	5.5%	8.3%	24.1%	19.7%	9.1%	5.1%
Processed food – Urban	17.7%	13.9%	16.9%	22.4%	24.8%	11.9%
Processed food – Imports	8.4%	8.1%	10%	12.3%	13.7%	6.6%
Manufactured good – Urban	9.2%	8.3%	7.4%	5.2%	7.9%	6.4%
Manufactured good – Imports	18.1%	20.4%	16.3%	20%	18%	20.4%
Non-tradables – Far	6.1%	14.5%	–	–	–	–
Non-tradables – Near	–	–	10.6%	8.5%	–	–
Non-tradables – Urban	–	–	–	–	17.3%	26.9%

Note: This table shows the final consumption vector at baseline. Columns refer to households (Agricultural – Far, Non-agricultural – Far, Agricultural – Near, Non-agricultural – Near, Wage-earning – Urban, Capitalist – Urban) and rows refer to goods (type of good and source).

C.4 The capitalist household

The capitalist household does not appear in the IFPRI SAM but rather is created to absorb items of income and expenditure in the national economy that cannot be booked elsewhere, given the restrictions of our model structure. Hence this household is the sole owner of capital and is thus the sole recipient of gross profits. Likewise, it owns the transport and distribution sector and therefore receives the rents accruing from the movement of goods from producers to consumers in different locations. Finally, as the only saving household in the model, all private savings are booked though the capitalist household which then allocates these to the accumulation of indexed domestic government debt and/or investment in tangible capital in the urban food processing and manufactured goods sectors. The capitalist household account is balanced by a residual 'net remittances' flow to the rest of the world.

C.5 The final spatial SAM

The final step consists in transforming the original IFPRI SAM fiscal and external balance accounts to a model-consistent form. Most of the required adjustments follow directly from the transformations to the household production and consumption accounts described above, but some final adjustments to tax revenues, expenditures and external balancing items are implemented to ensure a broad alignment with the fiscal and external balance accounts reported for 2018 by the IMF (see IMF (2022)). The resulting spatial structure of the model economy and factor intensity of production at baseline are summarized in Table 2, and Table 3 reports the associated fiscal and external balance at baseline.

Table C2: Factor allocation at baseline

Region	**Sector**	**labor**	**Land**	**Capital**
Far rural	Staple crop	42%	59%	-
	Cash crop	5%	19%	-
	Non-tradables	9%	-	-
Near rural	Staple crop	16%	19%	-
	Cash crop	2%	4%	-
	Non-tradables	3%	-	-
Urban	Processed food	6%	-	46%
	Manufacturing	4%	-	54%
	Non-tradables	13%	-	-

Note: This table shows the relative allocation of labor, land, and capital across the nine spatially differentiated sectors of production at baseline.

D Methodological appendix

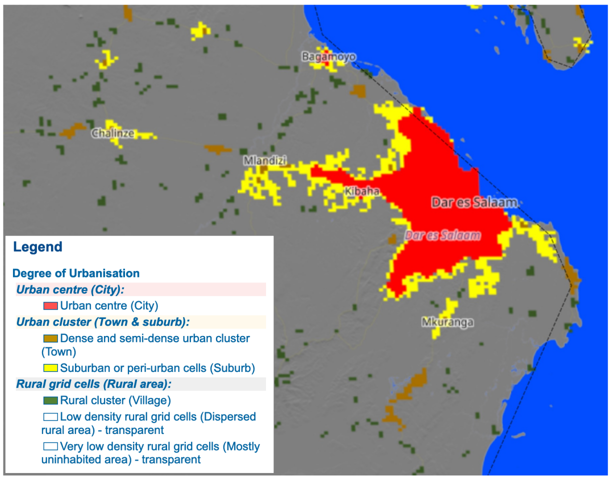
D.1 Mapping locations to model regions

We use the Global Human Settlement Layer's (GSHL) Degree of Urbanization (DoU) classification to map households' geo-coordinates in the Living Standards Measurement Study's (LSMS) data to model regions. The LSMS data includes (modified) household coordinates, which can be mapped to one of the GHSL's seven DoU categories. We subsequently map these seven DoU categories to one of the three model regions to connect the geo-coded data to the stylized model.[36]

Table C1: Mapping Degrees of Urbanisation (DoU) clusters to model regions

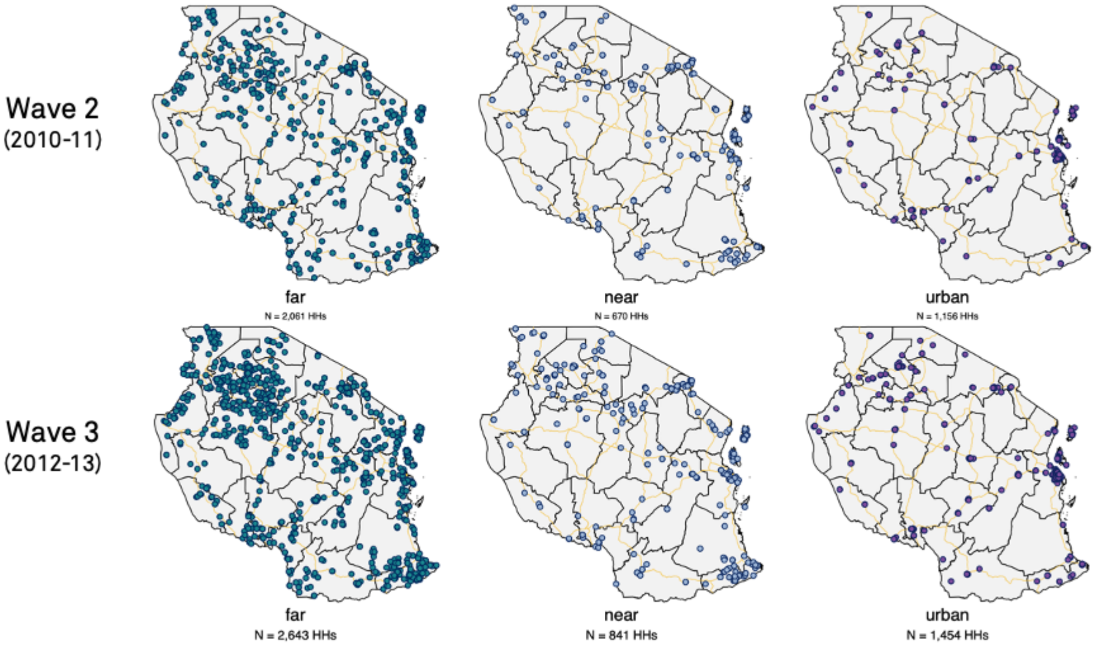
Model Region	**DoU Grid Cell**
Urban region	Urban Centre (30)
	Dense Urban Cluster (23)
	Semi-Dense Urban Cluster (22)
	Suburban Or Peri-Urban (21)
Near rural region	Rural Cluster (13)
	Low Density Rural (12)
Far rural region	Very Low Density Rural (11)
N/A	Water (10)

Figure C1: Global Human Settlement Layer (GHSL) Degree of Urbanisation



[36]The mapping from household coordinates to DoU categories was conducted by Shraddha Mandi for a forthcoming working paper ("Urban-Rural Definitions and Spatial Income Gaps," by Douglas Gollin, Martina Kirchberger, David Lagakos, and Shraddha Mandi). We are grateful to the authors for sharing their data and code.

Figure C2: LSMS household locations by type of region



D.2 Classification of crops

To classify crops into export cash crops and staple food crops, I use data on agricultural production and trade from FAOSTAT to calculate the export share and import share for each crop. The export share indicates the proportion of domestic production that is exported to the rest of the world. The import share, on the other hand, gives imports relative to domestic production. Crops that have a high export share (> 50%) and a low import share (< 10%) are subsequently classified as export cash crops. Exceptions to this methodology are seed cotton, sugar cane and sisal, where raw production quantities cannot directly be linked to export and import quantities, as these crops are not traded in raw form. Instead, they are processed into e.g. cotton lint, refined sugar and fiber prior to being traded. I still classify cotton, sugar cane and sisal as export cash crops in the context of Tanzania, based on UN Comtrade statistics. The following ten crops are classified as export crops in the Tanzanian data:

Table C2: Export (cash) crops in Tanzania, 2010-20

	Item	Area	Production	Exports	Imports	Exports %	Imports %
1	Cashew nuts	575,581	182,137	174,114	1	96	0
2	Seed cotton	378,332	237,509	-	-	-	-
3	Coffee, green	187,685	55,664	52,033	7	93	0
4	Tobacco	123,100	93,826	69,622	2,414	74	3
5	Chick peas	83,121	67,664	46,785	121	69	0
6	Sugar cane	50,615	3,063,594	-	-	-	-
7	Sisal	50,254	34,308	-	-	-	-
8	Tea	19,197	39,840	25,805	252	65	1
9	Cocoa, beans	14,708	10,455	9,667	1	92	0
10	Pepper	956	443	256	33	58	7

Note: All values in this table are calculated from FAOSTAT data. Crops are ranked by Area (area harvested measured in hectares). Production, Exports and Imports are 2010-2020 mean quantities in tonnes. Exports (Imports) % shows the mean export (import) quantity as a percentage of the mean production quantity. All crops refer to unprocessed raw crops (for example, cashew nuts are in shell and tobacco is un-manufactured). Export and import quantities for seed cotton, sugar cane and sisal are missing because these crops are not traded in raw form. Instead, they are processed into e.g. cotton lint, refined sugar and fiber prior to being traded.

D.3 Classification of food items

Table C3: Classification of food items – Staple foods & processed foods

Panel A: Staple foods		
bananas (cooking), plantains	groundnuts	rice (paddy)
bananas (ripe)	irish potatoes	seeds
cashew, almonds, other nuts	maize (flour)	starches (other)
cassava (dry/flour)	maize (grain)	sugarcane
cassava (fresh)	maize (green, cob)	sweet potatoes
cereals (other)	millet and sorghum (flour)	vegetables (green)
coconuts	millet and sorghum (grain)	vegetables (other)
fruits (citrus)	pulses	wheat (flour)
fruits (other)	rice (husked)	yams, cocoyams
Panel B: Processed foods		
beer	fish and seafood (processed)	milk (fresh)
birds and insects (wild)	fish and seafood (fresh)	milk products
bread	fruits (canned)	salt
brews (local)	honey, syrups, jams	soft drinks
buns, cakes, biscuits	macaroni, spaghetti	spices (other)
butter, margarine, ghee	meat (beef)	sugar
cereal products (other)	meat (goat)	sweets
coffee and cocoa	meat (pork)	tea (dry)
cooking oil	meat (poultry)	tea, coffee (prepared)
eggs	meat products (other)	vegetables (processed)
fish (packaged)	milk (canned), milk powder	wine and spirits

Note: This table gives an overview of the classification of food items into either staple foods or processed foods for the purpose of calculating budget shares to parameterise the utility function. The classification is loosely based on Regmi et al. (2005). The overview is meant to be illustrative; Item codes are omitted and some items are summarised into broader categories to condense the information, for instance "fruits (other)".

PUBLICATIONS