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Agriculture, Aid and Economic Growth in Africa

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Abstract

How can foreign aid to agriculture support economic growth in Africa? This paper constructs a geographically-indexed applied general equilibrium model that considers pathways through which aid might affect growth and structural transformation of labor markets in the context of soil nutrient variation, minimum subsistence consumption requirements, domestic transport costs, labor mobility and constraints to self-financing of agricultural inputs. Using plausible parameters, the model is presented for Uganda as an illustrative case. Three stylized scenarios demonstrate the potential economy-wide impacts of both soil nutrient loss and replenishment, and how foreign aid can be targeted to support agricultural inputs that boost rural productivity and shift labor to boost real wages. One simulation shows how a temporary program of targeted official development assistance (ODA) for agriculture could generate, contrary to traditional Dutch disease concerns, an expansion in the primary tradable sector and positive permanent productivity and welfare effects, leading to a steady decline in the need for complementary ODA for budget support.

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Agriculture, Aid and Economic Growth in Africa *

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How can foreign aid support economic growth and poverty reduction in sub-Saharan Africa (hereafter "Africa")?[1] An assessment of this important question can begin by recognizing three points. First, the majority of Africa's extremely poor people still live in rural areas and primarily work on smallholder subsistence farms for their livelihoods. These settings are categorized by low and slow-growing agricultural value added per worker, low staple crop yields, soil nutrient depletion and low levels of modern input use (Stoorvogel and Smaling 1990, McArthur 2015). Yet input technologies now exist – such as fertilizer, modern seeds, land management and small-scale irrigation – to boost productivity in these areas. Among other factors, Malawi's post-2005 results in doubling average national maize yields through an aid-supported input subsidy program prompted considerable analysis regarding the potential merits of increasing public finance to support small-holder agriculture throughout Africa (e.g., Diao et al. 2008; Duflo et al. 2011; Chirwa and Dorward 2013; Jayne and Rashid 2013).

Second, there is considerable evidence indicating that agricultural growth has had important aggregate effects in reducing global poverty, especially extreme poverty (Bourguignon and Morrison 1998, Gollin et al. 2002; Christiaensen et al. 2011). Some researchers posit that the role of agriculture has been fundamental, if underappreciated, in promoting growth in non-agricultural sectors, including through channels of structural transformation from low productivity rural sectors to higher productivity urban sectors (e.g., Bezemer and Heady 2008; de Janvry and Sadoulet 2009; McArthur and McCord 2017). However, the precise channels through which public investments in agriculture might promote sectoral outcomes remain inadequately understood, prompting some researchers to caution against prioritizing agriculture compared to other sectors (Collier and Dercon 2013; Dercon and Gollin 2014).

Third, an extensive cross-country empirical literature has long grappled to specify the conditions and pathways through which aid, as a source of public finance, might support growth (e.g., Hansen and Tarp 2001, Werker et al. 2009, Arndt et al. 2015, Galiani et al. 2017). A subset of that literature has focused on such questions in the African context (e.g., Collier and Gunning 1999, Sachs et al., 2004, Gomanee et al. 2005). Econometrically, one of the core challenges is to distinguish between the respective purposes of different types of aid. Clemens et al. (2012), for example, separate out "early impact" aid that supports sectors like roads, energy, agriculture and industry, any of which might be expected to boost growth in the short to medium term. This is distinguished from other social sector activities like education, health, water and humanitarian assistance, "whose growth effect might arrive far in the future or not at all" (p. 599). The authors find a positive average relationship between aid and growth, but the results have been questioned by Roodman (2014), leaving room for argument.

These debates remain important, but their common emphasis on cross-country empirical relationships can only provide limited insight regarding the actual economic channels through which aid might support growth, poverty reduction, and labor's structural transformation toward higher productivity sectors in countries where the majority of people still live in rural areas, and where the primary economic activity remains staple crop farming. Even among "early impact" channels, aid for agriculture might initiate different structural dynamics than aid aiming to support energy systems or manufacturing. Moreover, given the emphasis that agronomic science has also placed on the central importance of soil nutrients to increasing African agricultural productivity (Stoorvogel et al. 1993, Sanchez 2010), it is highly relevant to consider how soil nutrient dynamics interact with broader agricultural and economic dynamics. There is therefore merit in considering the channels through which publicly-financed agricultural input support programs, potentially backed by foreign aid, could generate economy-wide outcomes. That is the aim of this paper.

To explore these dynamics, the paper introduces a simulation model for considering how soil nutrient loss can promote stagnation in a predominantly rural African subsistence economy and, conversely, how "green revolution"-type input support (i.e., aiming at a major increase in smallholder productivity) can prompt accelerated labor shifts across tradable and nontradable sectors. In the model, farms also need to meet a minimum subsistence level of food production, which is linked to potentially variable soil nutrient balances across geographies. A public subsidy helps to overcome farm-level constraints to self-financing of inputs. Most low-income country governments cannot afford to finance an input package through their own budget envelopes, so the model assumes this to be financed by official development assistance (ODA). A distinction is drawn between this ODA targeted for agricultural inputs and other "cash" ODA allocated to general budget support.

A green revolution-type agricultural productivity boost in the form of a doubling or more of staple crop yields would mark a tremendous direct supply-side structural change in a typical African economy. Because cereals and other staple foods in subsistence economies are mainly consumed on farms and in local markets, they are overwhelmingly nontradable goods with locally determined prices. A boost in supply should have strong deflationary pressures for the majority of the population's main consumption good while also spurring the allocation of labor and investment in an export-oriented cash crop sector. Therefore, unlike ODA for consumption or for investments with small supply-side effects, ODA increases to support an African green revolution might have anti-Dutch disease effects, contrary to the concerns of Rajan and Subramanian (2008, 2011).

The paper builds on the logic presented in Adam and Bevan's (2006) careful consideration of aid's supply-side productivity effects in a model calibrated to Uganda. In a migration-free model with Engel curve attributes, they focus on public-infrastructure-induced productivity spillovers and learning by doing in the export sector. Their model shows that welfare effects and real exchange rate dynamics are highly sensitive to the location of productivity effects and the composition of domestic demand. It emphasizes aggregate linkages to rural productivity in agricultural sectors, but does not explore these dynamics in detail.

We take up that challenge by building a subsistence threshold-based framework that shows how a poverty-trap dynamic can take shape in the presence of low-input agriculture and soil nutrient depletion. The model presented here does not aim to provide specific empirical results or point estimates. Instead, in line with the arguments of Robinson and Lofgren (2005), it aims to outline directions of medium-term structural shifts. Some aspects are similar to the nontradable agriculture analytical model in Matsuyama (1992), although here staple foods are treated as nontradable due to the reality of subsistence food economies with low private and public capital stocks, rather than as a function of overall economy openness. Indeed, one important part of our model is the ability for labor to shift easily between nontradable (food) and tradable (cash crop) sectors while remaining on farm.

The approach presented here differs from Lofgren and colleagues (2002), who follow the Dervis, de Melo and Robinson (1982) tradition of a standardized, mixed-complementarity computable general equilibrium (CGE) model, including a monolithic and exogenous public sector.[2] It also differs from the Poverty and Economic Policy Research Network (PEP) standard model (Decaluwé et al. 2009), which has a nested production structure and excludes home consumption, and from other Africa-focused macroeconomic models that have emphasized social development outcomes. For example, Agenor and colleagues (Agenor, Bayraktarb and El Aynaoui 2005; Agenor, Bayraktarb and Pinto 2005) and Pinto and Bayraktarb (2005) model the real economy through a single representative sector with a parameterized elasticity on poverty.

The Maquette for Millennium Development Goals Simulations (MAMS) model originally developed by Bourguignon and colleagues (2004) was novel for its decomposition of government sectors, emphasizing interactions between labor markets, infrastructure, and the achievement of outcome targets for poverty, education, health and water and sanitation. Its major contribution is the ability to show the evolution of intermediate outcomes en route to internationally-agreed development goals and highlight the implications of sequencing investments among sectors (Bourguignon and Sundberg 2006a, 2006b). The original MAMS model had a single representative productive sector, which did not permit evaluation of subsistence dynamics, although more recent applications have incorporated the core Lofgren et al. (2002) framework as the basis for evaluating more detailed analysis of productive sectors (Lofgren et al. 2013).

Some previous models have integrated the biophysical aspects of agricultural productivity into a developing country CGE framework. For example, Alfsen and colleagues (1997) use Aune and Lal's (1995) Tropical Soil Productivity Calculator in a 17-sector closed public sector model to show the contribution of soil nutrients to the growth of gross domestic product (GDP). A limitation of that model is that it does not include a ceiling for possible soil nutrient accumulation and does not allow for the practical reality of zero fertilizer use among large numbers of small-holder farmers, because the fertilizer term enters as a simple input in a Cobb-Douglas production function and zero input implies zero output. Wiig and colleagues (2001) pursued a comparable strategy to introduce soil degradation as a time-dependent Hicksneutral productivity coefficient in the agricultural production functions. Meanwhile Holden and colleagues (2005) add soil nutrient dynamics to a sophisticated multi-product household production and welfare assessment in the Ethiopian highlands.

The most similarly green revolution-spirited CGE approach to the model in this paper is presented by Breisinger and colleagues (2011), which extends the approach of Lofgren et al. (2002) to include within-country disaggregation by agroecological zone, crop market and income group. Their model is applied to Ghana, and a green revolution is achieved through exogenously defined total factor productivity improvements to achieve target yields, prompting greater input use through factor markets. Foreign savings are fixed, so incremental investments are all financed through domestic resources.

Our model illustrates pathways through which targeted investments in agriculture, supported by ODA, could plausibly promote structural transformation in Africa. Indicative parameters for Uganda are used to show representative dynamics. The economy is suitable for analysis because its labor is still overwhelmingly in rural areas and remains largely focused on staple food production. Rural productivity remains extremely low and a considerable share of the country still lives in extreme poverty. Spread across four major regions, the country's agricultural systems have major variations across local climatic zones, soil types and soil nutrient flows over time. Soil nutrient losses have been considerable, and nutrient stocks have fallen below critical levels in many parts of the country.

The rest of the paper proceeds in four sections. Following this introduction, section I presents the general equilibrium model. Section II presents a range of scenarios using the model. Section III discusses some key insights generated by the simulations. A final section concludes.

I. Model Description

The model has several key attributes aligned with many low-income African economies. The first is a dominant factor of rural subsistence economic stagnation, with low savings and flat incomes in the absence of productivity increases in agriculture. The second is a minimum subsistence food requirement that underpins the thresholds for agricultural diversification, savings and labor switching to other sectors. The third is a soil nutrient depletion and accumulation process that directly feeds into agricultural production functions. The fourth is labor mobility from rural to urban areas, with migration parameterized to respond to relative wages.

The fifth relevant attribute is a constraint to self-financing agricultural inputs, like fertilizer, among small-holder farmers. The sixth is a road-building component and Samuelson-style "iceberg" transport cost structure that directly affects relative prices for agricultural outputs and decreases in the presence of road improvement. The seventh attribute is the possibility of geographic variation in productivity levels and locations of production, including variation in soil nutrient flows and transport infrastructure.

The model follows a recursive structure over 10 periods, with decisions depending on past and present periods but no forward-looking dynamics. The productive economy includes both tradable and nontradable sectors, with no intermediate goods. The nontradable sectors are staple food production, rural services and urban services, all of which have locally determined prices. The two domestic tradable sectors are cash crops and manufacturing, both of which are assumed to have fixed numeraire tradable prices, zero domestic consumption and infinite elasticity of demand. In reality, Uganda's manufacturing sector is very small and includes a focus on import substitution, so the assumption of full export orientation is made for the purposes of simplification within the model's core focus on rural and rural-urban dynamics. Implicit in the model is a fixed nominal exchange rate, so changes in domestic prices indicate changes in the real exchange rate. There is also an imported sector that provides consumption goods and capital goods for investment with infinitely elastic supply at fixed prices.

The model is constructed to permit flexibility around the number of urban and rural geographic units. Simulations presented here include four rural units—mapping to Uganda's Eastern, Western, Central and Northern regions—plus one urban unit, Kampala. Historically Kampala has accounted for approximately 85 percent of the country's urban economic activity so this is assumed to be a reasonable simplification of the underlying national economy. The two agricultural sectors and the rural service sector are only active in the model's rural areas. Manufacturing and the urban service sector only take place in the city. Food is produced in the rural sectors to feed both the local rural population and the urban population. Table 1 describes the geographic indexing of productive sector activities. Table 2 shows the corresponding information for public sector activities.

The model's emphasis on Engel's law and non-homothetic preferences links directly to its rural-urban divide. Rural staple food production must satisfy a minimum level of aggregate per capita food requirements for both rural and urban populations. A savings-driven neoclassical closure applies a fixed savings rate on incomes above the minimum food basket, and private saving is set equal to productive sector investment. Capital is immobile across regions, although foreign investment is possible in the urban manufacturing sector.

In addition to the option of supporting agricultural inputs, the formal public sector includes considerable rural road building alongside urban public administration and other services like health and education. The government's fiscal balance is financed by external ODA “cash,” equivalent to budget support. This budget support is fully separate from ODA-financed agricultural inputs, which are imported on a pre-planned basis across a 10-year time horizon. The endogeneity of cash ODA differs from similar models that typically frame official foreign savings as fixed. This allows comparison of ODA implications for different scenarios. The model structure allows the option to integrate both capital and recurrent government spending accounts, with the possibility for multi-year budget variations by geographic zone, subsector and import content.

Labor is fully mobile from rural to urban regions, although not across rural regions, and responds to relative real incomes. Total labor is fixed. Implicit in the model is an assumption that all labor has a home rural region and that each rural region has a fixed total implicit population of origin, so even the labor present in the urban area in the first period is linked to one of the four rural areas. In allocating their labor, rural households not directly hired by the public sector can choose between working in staple foods, cash crops, rural services, or migrating to the urban area, where manufacturing and urban services are the productive sector options. Prices are free variables playing market clearing functions, with rural prices segmented from urban prices.

Real incomes, net of food, are equilibrated instantaneously in the rural sectors and over time between rural and urban sectors. Thus the most fundamental impulses driving labor markets are productivity in staple foods, relative food prices between rural and urban areas, and real income differences between rural and urban areas. Food prices are affected by transport costs, which are in turn determined by the scale of the road network. As the road network increases, transport losses decrease and less total food production is required to feed the population.

The full details of the model are presented in the supplemental appendix, including all equations, variables and parameters. Here we highlight some of the most important structural equations and dynamics. As a notation convention, model variables are listed in *CAPITAL* letters and parameters are listed in lowercase italics (*e.g.*, *theta*).

Agricultural Production

The model captures basic soil nutrient dynamics in a manner that allows soil-relevant estimation of yields with relative simplicity while focusing on key policy decision variables. As shown in EQ.1.1 and EQ.1.3, the agricultural production functions for food, *F*, and cash crops, *CC*, are Cobb-Douglas and indexed to each rural region.[3] Land is considered a fixed parameter in the immediate term and presented without an exponent, as are the *theta* productivity terms. The coefficients on capital and labor therefore sum to less than 1, and labor (here *LF* and *LCC*) serves as the market clearing factor. Agricultural diversification is achieved when labor shifts from staple crops to cash crops.

There are two elements of note in the agricultural equation structure. The first is the soil productivity parameter, *S,* which itself follows a logistic functional form in EQ.1.5, with the numerator defined as an upper-bound level of soil productivity (*uppersoil*). The denominator is partly determined by the slope of the underlying S-curve, set by *rho,* which has a value of 1.5 in the simulations. (Values greater than 1 imply steepness closer to the top of the curve.) The other part of the denominator is determined by *EXPNUT*, which represents the exponential of cumulative recent nutrient flows *NUTSUM*, as per equation EQ.1.6. The net nutrient flows in a period (*NETIN*) are defined in EQ.1.9 by the inflow of external inputs alongside an exogenous rate of nutrient loss, *nlossrate*.[4]

The second element to note in EQ.1.1 and EQ.1.3 is that agricultural inputs enter the equation as a single (1+*INPUT*) linear term in order to accommodate the common African scenario of zero initial modern input use, especially fertilizer. Conceptually, the *INPUT* term represents Leontief-style complementarities among a package of yield-boosting inputs, such as fertilizer, fertilizer-responsive seeds, and inputs for land management that might reduce erosion and promote soil-based "green water" efficiency (Rockström et al. 2009). The *INPUT* term therefore has a dual effect. It provides both a direct productivity boost in the current year's output, as indicated directly in the production function, and an indirect boost through the following year's underlying soil productivity.

Farmers are implicitly choosing to allocate their labor among food and cash crops within each period, while using the same input mix across both types of crops and allocating investments only to cash crop capital (*KCC*). Water is a crucial factor for agriculture too, but given the rain-fed nature of most African agriculture and the order-of-magnitude larger capital outlays required even for small-scale "blue water" irrigation compared to "green water" (*ibid.*), we assume those to be incorporated in *KCC*.

$$F_{i,t} = S_{i,t} * thetaf_i * land_i * (1+INPUT_{i,t}) * LF_{i,t}^{alphaf} * kf_i^{betaf} \qquad \text{(EQ.1.1)}$$

$$CC_{i,t} = S_{i,t} * thetacc_i * land_i * (1+INPUT_{i,t}) * LCC_{i,t}^{alphacc} * (kcscale * KCC_{i,t})^{betacc} \qquad \text{(EQ.1.3)}$$

$$S_{i,t} = \frac{uppersoil_i}{1 + rho * EXPNUT_{i,t}} \qquad \text{(EQ.1.5)}$$

$$EXPNUT_{i,t} = e^{-NUTSUM_{i,t}} \qquad \text{(EQ.1.6)}$$

$$NUTSUM_{i,t+1} = NUTSUM_{i,t} + NETIN_{i,t} \qquad \text{(EQ.1.7)}$$

$$NETIN_{i,t} = INPUT_{i,t} – nlossrate \qquad \text{(EQ.1.9)}$$

$$INPUT_{i,t} = min\ (1, max\ (0, (kcscale * (KCC_{i,t} – ((1 + khurdle) * kcc0_i)))) + greenoda_t) \qquad \text{(EQ.1.10)}$$

The equation for input use (EQ.1.10) is central to the model. The amount of input use takes a value ranging from zero to one, meaning that the (1+INPUT) multiplier term in EQ.1.1 and EQ.1.3 can take an absolute value ranging from one to two. Market-purchased input use is restricted by a household poverty constraint. We deploy a minimum capital requirement in cash crops, *khurdle*, to reflect a wealth level required to afford inputs at the beginning of a planting season and bear the risk of adverse farm shocks, in addition to a collateral requirement for borrowing. Alternative income-based constraints to purchasing inputs could also be deployed without significantly changing the model's core dynamics.

The final term in EQ.1.10, *greenoda*, represents the ODA-financed package of green revolution-supportive inputs, as a supplement to the market-based input purchases. The agricultural inputs are all presumed to be imported with fixed numeraire prices, so the *greenoda* variable can be interpreted as representing both a physical amount and a financial amount. As mentioned earlier, this targeted agricultural ODA is different from the budget gap-filling aid for budget support (*CASHODA*) described below, since the agricultural ODA is set in advance as an exogenous policy parameter for each period. This allows for a multi-year input support program that can also have a pre-committed phase-out over time.

Food Markets

Food market-clearance helps drive the model too. Urban food demand in Kampala, *FKAMP*, is the product of urban labor, *LU*, and food requirements per capita, *phi* (EQ.3.1). This *phi* parameter is also pivotal to the model's dynamics. Conceptually, it represents an amalgam of physical units across staple crops.[5] For purposes of intuition, this can be considered as the volume representing a required minimum of staple food calories per capita. In the food markets, urban food supply, which equals urban food demand, is defined as the sum of all rural areas' food surpluses minus the losses (*TLOSS*) incurred in transporting food from the rural areas to the urban areas (EQ.3.2). Each rural region's food surplus (*FSURP*) is defined as its food production minus the product of the region's labor size and food requirements per capita (EQ.3.3). The on-farm crop choice optimization occurs by equilibrating the marginal product of cash crops and the marginal product of staple food (EQ.5.8 in appendix)

$$FKAMP_t = phi*LU_t \tag{EQ.3.1}$$

$$FKAMP_t = \sum_i FSURP_{i,t} * (1 - TLOSS_{i,t}) \tag{EQ.3.2}$$

$$FSURP_{i,t} = F_{i,t} - phi*LR_{i,t} \tag{EQ.3.3}$$

Transport Costs and Prices

Iceberg transport cost adjustments help drive the model's allocation of labor and production across sectors and among rural and urban areas. Agricultural transport losses from rural to urban areas are an inverse function of the rural road stock, with initial transport losses indexed to each region (see EQ.4.1 in appendix). The urban price of food is more expensive than the rural price of food by an amount scaled to the degree of transport losses (see EQ.4.2). The farm-gate price of cash crops, as internationally priced goods, has a similar inverse relation to transport costs. The manufactured good and imported agricultural inputs are assumed to have a sufficiently high value per weight that domestic transport costs are not significant.[6]

Labor Income and Migration

The real wage for urban services (*RWSU*) and the manufacturing sector (*RWMAN*) are set as the nominal wage minus the cost of urban food requirements, all adjusted for the non-food urban consumer price index, *CPINFU*, as in EQ.5.10. The real rural service wage is set similarly using each rural region's local food price and non-food price index, *CPINFR* (see EQ.5.11 in appendix). As shown in EQ.5.12, the real per capita farm income, *YFARM*, includes the sum of agricultural households' food crop income (*VF*) plus the value added from cash crop income (*VCC*), minus the equivalent cost of the minimum food need for farm workers (*LFARM*) and the cost of market-purchased inputs.

$$RWSU_t = \frac{WSU_t - phi * PFU_t}{CPINFU_t} \tag{EQ.5.10}$$

$$YFARM_{i,t} = \frac{VF_{i,t} + VCC_{i,t} - phi * PFR_{i,t} * LFARM_{i,t} - (INPUT_{i,t} - greenodq_i)}{CPINFR_{i,t} * LFARM_{i,t}}$$

(EQ.5.12)

The urban labor equilibrium is set by equating the real wage in manufacturing with the real wage in urban services. Within rural regions, real service wages are equated with real farm incomes, and mobility is instantaneous across sectors. Migration is a function of rural-urban wage differentials, which are minimized over time due to migration.

Disposable Income, Savings and Consumption

Disposable income is set as the sum of sector incomes net of staple food consumption, market-based agricultural input purchases, and taxes (see EQ.7.1 and EQ.7.2 in appendix). The savings equations assume fixed savings rates within urban and rural areas, respectively, set as a fraction of disposable income (see EQ.7.5 and EQ.7.6). The model also assumes a minimum level of nonfood consumption, *cmin*, comprised of both local services and imported goods. If disposable incomes are below *cmin*, then saving is zero. Consistent with the possibility of a savings-based poverty trap, the net savings rate therefore increases as households cross an average income threshold that pays for both minimum food needs and the minimum consumption basket.

External Balance

Total exports are equal to total cash crop production (net of domestic transport losses) plus total manufacturing production. Urban private investment imports are equal to the sum of urban saving plus all foreign direct investment, which is in turn determined by the difference between the local rate of return and the exogenous global rate of return. Rural private investment imports are equal only to rural savings. Public investment goods for roads and other social sectors are imported, so total imports (*IMPORT*) are given in EQ.8.6 as the sum of agricultural input use; imported rural and urban consumption goods (*IMPRC* and *IMPUC*); imported rural and urban investment goods (*IMPRI* and *IMPUI*); plus government imports for general investment (*PUBINV*), road investment (*ROADINV*) and commodities (*TOTIMPG*).

$$IMPORT_t = \sum_i INPUT_{i,t} + \sum_i IMPRC_{i,t} + IMPUC_t + \sum_i IMPRI_{i,t} + IMPUI_t$$

$$+PUBINV_t + ROADINV_t + TOTIMPG_t \qquad \text{(EQ.8.6)}$$

Public Sector and Government Balance

Government tax revenues (*TAX*) are collected on after-food incomes across all sectors, including urban and rural government worker incomes (see EQ.10.1 in appendix). Total public expenditures (*TOTEXP*) are financed by tax revenues and budget support, *CASHODA*, as shown in EQ10.2. As mentioned, this budget support ODA is distinct from the ODA for targeted agricultural inputs. Total public expenditure is the sum of both recurrent expenditure and capital expenditure, including road-building, which affects transport costs. [7] Recurrent public sector costs are defined as the sum of labor costs and commodities and are assumed to include operations and maintenance.

$$TOTEXP_t = TAX_t + CASHODA_t \qquad \text{(EQ.10.2)}$$

II. Scenarios

We present three stylized scenarios to illustrate the model's core dynamics. As shown in Table 3, the first scenario provides an analytical baseline. It includes no soil productivity parameter and no targeted ODA for agriculture, so movements over 10 years are primarily driven by savings, investment and depreciation across sectors. The second scenario introduces the soil productivity and nutrient flow parameters in the agricultural production functions in order to examine how nutrient losses might affect broader outcomes. The third scenario builds on the second by introducing targeted ODA for agricultural inputs. We dub this the "green revolution" scenario, recognizing that this is an analytical simplification of the actual mix of activities that might enable an African green revolution in practice. The external support program starts in Year 3, and then is gradually phased out over the following five years, such that it decreases to zero for Years 8, 9 and 10. All scenarios include the same annual improvements in the road network.

The model is applied using General Algebraic Modeling System (GAMS) software and the "CONOPT" nonlinear solver. Indicative parameters are set to match the general nature of the Ugandan economy as of the mid-2000s (see Appendix S4). More precise and detailed country-specific refinements could be applied as desired. For the purposes of the illustrative scenarios presented here, the model is structured to match the country's four main regions. Kampala is located within the Central region, so Central has the lower initial transport loss when sending food to the urban area.

For each scenario, Table 4 reports values for a selection of key variables, including: soil productivity, modern agricultural input use, labor movements, prices, real wages, savings, capital stocks, government aggregates, external balances, aggregate aid flows, and total private output (i.e., excluding the government wage bill) indexed to first period prices. Specifying unit measures can commonly present a challenge in an analytically distilled CGE model like this one. For purposes of intuition, each labor unit can be roughly interpreted as representing a million workers, while prices and economic aggregates can be interpreted, as previously mentioned, in domestic currency terms relative to a fixed nominal exchange rate and constant numeraire tradable prices. Among the rural zones, Table 4 only presents Western region values for the sake of space. Each region follows slightly different dynamics, guided by initial conditions, but any region's values demonstrate similar trends for each scenario.

Scenario 1: The Baseline

The baseline scenario shows general stagnation in a low-productivity rural economy. The majority of farm families remain stuck on farms, and labor moves out of food production very slowly over time, with small increases in cash crop labor and otherwise gradual migration to rural services and urban areas. Manufacturing substitutes a growing workforce for its declining capital stock over time. There is almost no modern input use, which is a good general approximation of the historical situation in Uganda.

The rural and urban areas have distinct price dynamics. Food prices vary across rural areas; in period 1 they are 37 percent higher in the Central region than in the Northern region, due to varying initial transport losses, while Western and Eastern region prices are within that range. Food is approximately twice as expensive in the urban compared to rural areas. Over the 10-year period, food prices climb from 3 to 11 percent across rural regions and decline nearly 8 percent in the urban area as the road network improves. The rural and urban non-food CPIs (*NCPI*) are more similar to each other as services are provided locally without transport costs. The price of rural services increases slightly over time as rural consumption grows, while remaining fairly constant in urban areas. Real wages are presented only for the service sectors because there is cross-sector wage equilibration within each respective rural and urban area. The urban real wage is 36 percent greater than its rural Western counterpart in the first period, with the gap declining to 28 percent by the end of 10 years.

The national savings rate grows modestly over 10 years, from 11.0 percent to 11.4 percent, driven mainly by rural savings. In rural areas a slight majority of investment is directed toward cash crops over services, and is adequate to outweigh depreciation and lead to slow capital accumulation. But even this is not generally enough to cross the threshold for agricultural input use, so only two regions (Eastern and Western) are able to start using even the smallest amount of inputs by Year 10. In the urban areas, local savings are allocated evenly to domestic services and manufacturing, the latter supplemented by FDI. In this scenario, capital depreciation is prevalent across the service and manufacturing sectors.

In the government accounts, 60 percent of the budget is covered by domestic tax revenues, which grow faster than expenditures. The remainder is financed by ODA budget support. External balances mirror the government balance, with a trade deficit equal to 14 percent of total imports. Initial exports are equivalent to 40 percent of GNP, which is higher than Uganda's actual share, but nonetheless a reference point for the subsequent scenarios. Foreign direct investment is small, reflecting the low return on capital in the country and the low level of investment in the manufacturing sector. The bottom row of Table 4 shows the lack of overall growth in the real economy over the course of a decade, as an index of real private output.

Scenario 2: Soil Productivity

This scenario introduces a small amount of annual nutrient variation in the agricultural production functions, adding up to less than 10 percent cumulative soil productivity loss over 10 years. The simulation is again not intended to offer false precision regarding quantitative effects, but it does demonstrate the extent to which a small loss in soil productivity can have considerable negative economy-wide effects, consistent with the findings of Marenya and Barrett

(2009) and Matsumoto and Yamano (2009). Compared to the preceding baseline, a marginal decline in agricultural productivity needs to be met by a shift in labor to food crops in order to maintain minimum economy-wide food production. This contributes to cash crop labor decreasing by more than a quarter over the full period. Total farm labor gradually increases, so the rural and urban service sectors also experience labor declines. Only manufacturing absorbs a slightly larger amount of labor than in scenario 1, although rural to urban migration now stops altogether by Year 10.

The other major implication for the economy is significant inflation in food prices, which climb 44 to 56 percent across the four rural regions. By Year 10, urban food prices are also 40 percent higher compared to those of the baseline scenario. The urban real wage drops by more than a third due to the higher food price, even as the rural real wage adjusts only slightly. The final year's national savings rate is only 9.1 percent.

In the government accounts, tax collections are flat and labor costs increase mainly due to increased service sector wages. By Year 10, the need for cash ODA is considerably higher than in scenario 1, covering nearly 43 percent of the full budget. In this scenario, physical cash crop production drops 20 percent over 10 years. A poverty trap is reflected in a 0.8 percent average annual decline in total private output over the decade.

Scenario 3: The Green Revolution Package

This scenario introduces the ODA-supported agricultural input package, *greenoda*, with starkly different outcomes compared to the previous two scenarios. The top row of Table 4 shows how this leads to an increase in the soil productivity parameter, which in turn provides a major boost to overall outcomes. Soil nutrients are replenished by both inputs and higher yields, so soil productivity jumps from 23 to 29 percent across rural regions, with growth rates leveling off once the support package is removed. The boost in staple food productivity frees up labor for cash crops and services in rural areas, while boosting migration into urban areas. Table 5 presents the scenario's simulation results for key variables across all 10 years in order to allow a more careful review of the dynamics.

The green revolution ODA package, summed across rural regions in tables 4 and 5, begins in Year 3 and gradually declines through to Year 7. Then it is withdrawn entirely in Year 8, prompting a temporary increase in staple food labor, but the downward trend then resumes as labor continues to move into all the other higher-paying sectors. By that point farmers are able to generate enough capital in cash crops to initiate a self-sustaining and growing agricultural input market in all rural areas. In other words, under reasonable parameters a temporary boost in targeted ODA for agriculture leads to a permanent boost in agricultural productivity.

Price dynamics form an important element of this scenario. By Year 7, food prices drop by at least 43 percent in all rural regions, and by 51 percent in the urban area. In the total consumption basket, this generally outweighs the non-food CPI increases of 5 to 15 percent across rural areas over the decade, while the urban non-food CPI increases by only 4 percent. By Year 10, real wages in rural services increase by 26 to 46 percent, and in urban services by 43 percent. These price trends demonstrate one way in which a targeted ODA support package might avoid traditional Dutch disease dynamics.

Meanwhile, savings receives a boost from the increase in disposable income, leading to a savings rate that grows to 14.9 percent by Year 10. Underlying real output grows 22.4 percent over the same horizon, for a compound growth rate of 2.0 percent per year. Major expansion of the exported cash crop sector drives a considerable share of the overall growth, again counter to Dutch disease-type concerns about aid hindering growth in key tradable sectors. Over the final three years, overall real growth rates in private output are -2.4 percent, 1.3 percent, and then 1.5 percent, respectively. By the end of the scenario, the underlying overall capital stocks across all sectors are able to halt, and in most instances reverse, declines experienced in the pre-green revolution years.

A major boost to tax revenues leads to rapid progress on the government balances. In the final year of the green revolution package, Year 7, budget support ODA (i.e., excluding the ODA for agricultural inputs) is less than 12 percent of government expenditures and only 1.6 percent of GNP. After a downward adjustment in Year 8, the tax revenue growth trajectory reinitiates in Year 9 and by Year 10 the government budget is again approaching full domestic financing.

III. Discussion

The simulations illustrate some of the dynamics that can be evaluated by considering specific pathways for targeting aid. Figures 1 through 6 compare the paths of some key variables across scenarios. The left panel of Figure 1 shows labor in cash crops in the indicative Western region. It demonstrates that the baseline (scenario 1) has relatively stable labor in cash crops. The introduction of a soil productivity loss function instigates a clear decline of labor in the sector, because labor must shift back to food production in order to meet the country's minimum needs. On the other hand, the green revolution scenario shows a rapid and sustained increase in tradable cash crop labor.

The right panel of Figure 1 presents the trends for labor in urban services. The baseline scenario shows a very gradual increase in the sector, but the soil nutrient scenario experiences a decline in urban (and rural) service labor due to the requirements for food production. Again, the green revolution prompts a 32 percent increase in urban service employment as its capital stock is bolstered through increased savings and higher farm productivity leads to a decline in the total number of farm workers.

Figure 2 shows trajectories for rural and urban food prices. A clear pattern emerges here too. The scenario 1 baseline sees general food price stability, but the incorporation of soil nutrient loss initiates a path of food price inflation in all regions, while the green revolution scenario sees the opposite effect. Part of this is driven by the model's structural imperative of meeting *phi*, the fixed underlying demand for food. The green revolution scenario's dual effects of labor moving from nontradable staple foods to tradable cash crops while food prices drop indicates progress through labor's movement into a higher value sector while also generating higher real incomes.

Figure 3 shows the nonfood CPI trends, with much smaller relative price fluctuations. Across all scenarios, the urban nonfood prices are relatively stable. Under the green revolution scenario, rural non-food prices in three regions (Central, Eastern, Western) climb 7 to 9 percent higher over the decade than under the baseline scenario, due to income growth, while the Northern region's prices climb only slightly less than under the baseline.

The implications for real exchange rate dynamics are informative. Once both food and nonfood prices are taken in to account, the agricultural intensification scenario shows an overall trend whereby imported agricultural inputs lead to a major expansion of cash crop exports alongside strong deflationary consequences for the rural populations, even while urban prices remain fairly constant.[8] The balance of price effects is determined by food's share in the consumption basket – which is large in this case. This occurs alongside an 84 percent expansion in cash crop exports. The ODA-related discussions of Dutch disease might need to introduce new jargon for the relative price effects caused by ODA targeted to staple crop productivity—"agro-ease"?

Figure 4 highlights another major outcome of interest by comparing real wages. Again, there is a stark distinction between scenarios defined by soil productivity loss versus smallholder productivity gains, including major differences in the urban sectors. In scenarios 1 and 2, rural real wages change very little over the decade, while in scenario 3, they increase by 26 to 46 percent across regions. The differences in urban outcomes are much starker. Under conditions of unaddressed soil productivity decline, real urban wages drop 34 percent. This compares to the green revolution strategy, wherein urban wages grow 43 percent. A key implication is that rural staple productivity trends can have large effects on urban living standards, independent of any direct interventions in the urban sector.

Figure 5 compares trajectories for real growth in (constant price) total private output, with Year 1 set to an index value of 100. The baseline scenario shows overall output stagnation and the soil productivity scenario shows a gradual long-term decline. Meanwhile, the green revolution simulation again shows a distinctly higher growth path. The jump in cash crop production drives the economy to a much higher new level of output as of Year 3. The economy continues to grow under the period of targeted agricultural support over Years 4 through 7, then experiences a downward adjustment in Year 8 before re-initiating a new positive growth trend.

Figure 6 presents perhaps the most dramatic results from the vantage point of considering potential consequences of different types of aid. The three lines indicate paths of aid for budget support, *CASHODA*, under the three respective scenarios. The contrasting directional dynamics are clear. The baseline scenario charts a long and slow decline in cash ODA as the economy experiences very gradual nominal growth. A simple extrapolation of the trend suggests it would take another several decades for the country to graduate from the need for budget support. Meanwhile the poverty trap dynamics in the soil productivity scenario require ongoing *expansion* of budget support ODA in order to fill the government's growing primary deficit.

The green revolution strategy follows an entirely different pattern. Under scenario 3, the decline in required budget support begins immediately in Year 3, due to the major growth effects the same year, when complemented by the introduction of considerable agricultural input support. The value of "total" (budget plus input support) ODA in Year 3 would be greater than the value under budget support alone, noting that the addition of two different types of ODA should be interpreted with caution. Then, as of Year 4, both budget support and *greenoda* are declining. After the final installment of agricultural input support in Year 7, there is a one-time increase in Year 8, when budget support increases to a level slightly higher than in Year 5, before resuming a downward trend again thanks to the cumulative growth effects.

One potential interpretation of Figure 6 is that modest soil nutrient loss in rural subsistence-dominated economies can drive the need for budget support's persistence, while nutrient supplementation can instead help drive its decline. In light of ongoing debates in the literature, we caution against interpreting this result to imply that aid-backed input support packages will automatically generate the latter outcomes. A growing evidence base is taking shape regarding the strengths and weaknesses of different input support programs under different contexts. Nonetheless, the result does illustrate a set of potential dynamics linked to an efficacious and time-limited input support program.

IV. Conclusion

This paper presents a macroeconomic model to enable insights regarding the channels through which basic issues of soil nutrients and targeted aid for agricultural input support could promote economic growth in Africa. The model makes a number of simplifying assumptions in order to focus on key issues of interest under three stylized scenarios. The most important dynamics pertain to the equilibrium impact of introducing a broadly scaled small-holder modern agricultural input support strategy, including complementary goods such as fertilizer and modern variety seeds. The model highlights the significant potential macroeconomic consequences of soil nutrient flows, both negative and positive, with implications for understanding the possible persistence of – or escape from – potential poverty traps in rural Africa.

Under plausible parameters, the model illustrates that a green revolution strategy could allocate a temporary boost in targeted ODA to generate permanent productivity, income and welfare effects in both rural and urban areas. The results highlight the importance of unpacking the different potential pathways and outcomes produced by different aims and purposes of allocating aid. It also underscores the risk of ignoring agriculture's potential role in stimulating improved living standards in other sectors, including urban sectors.

The model's empirical results demonstrate directions and pathways rather than precise point estimates. The model itself offers considerable range for scenario-building, parameterizations, and additional refinements that could enhance its ability to generate analytical insights around specific questions. Potential offshoot analyses could include, first, more nuanced labor mobility functions. While labor in the model is parameterized to migrate gradually between the rural and urban sectors, rapid mobility between the food and cash crop sectors is fundamental to the dynamics and to the positive general outcomes in the green revolution scenario. In reality, most farmers have a high degree of mobility between these two sectors in making planting choices on their own farms, but switching costs are likely nonzero, and the literature on farmer adoption patterns suggests that the instantaneous assumption is a simplification.

Second, the production functions could be refined in a number of ways. For example, the soil nutrient flows could be calibrated to specific regions, and more explicitly linked to production volumes and plant residues. The model also represents agricultural inputs as purely labor-saving, which is not necessarily the case because, for example, the introduction of fertilizer can require additional weeding and land management. The manufacturing sector could also incorporate more domestic and external factors affecting growth and learning-by-doing. The production functions could explore more sophisticated human capital structure or constant elasticity of transformation technologies where the additional modeling complexities would help to illuminate key topics of interest.

Third, the model excludes demographic effects, which are important due to shrinking land/labor ratios in many African countries and because investments in health, education and agricultural productivity are all likely to lead to increases in life expectancy and decreases in fertility rates. The government sector equations could be explored to examine these issues. Fourth, models could add a natural resource sector, in line with recent discoveries in countries like Uganda. Fifth, alternatives to the iceberg model could be considered for agricultural transport assumptions. Incorporating any of these issues would further augment the model's ability to inform macroeconomic analysis of relevant issues across African economies.

[1] Disclosure: In 2012, the first author gave speeches, for which he received compensation, at Mosaic AgCollege, at the Canadian Fertilizer Institute's annual meeting and at a CFI-organized sustainability event in Canada prior to the Rio+20 summit in Brazil. These speeches pertained to global agriculture and sustainability challenges. The aforementioned entities had no input whatsoever on the contents of either the original 2008 version of this study or on any of the research presented here.

[2] The core Lofgren, Harris and Robinson model has been applied to many countries— including Dorosh, El-Said and Lofgren's (2002) application to Uganda, which finds that positive agricultural productivity shocks provide less of a rural welfare boost than investments to decrease marketing margins.

[3] The non-agricultural productive sectors – urban manufacturing, urban services and rural services – also take a simple Cobb-Douglas form.

[4] This shorthand calculation for complex underlying nutrient flows facilitates solvability in the numerical model.

[5] In the simulations presented here, the *phi* value of 0.55 is set as a reasonable first approximation for the broader dynamics of the model. Future research could provide more precision on staple crop volume needs by region. Advances in soil nutrient mapping could also help develop location-specific and crop-specific farm productivity thresholds.

[6] Future research could explore adding further complexity to the model by including a domestic transport sector that incorporate product-specific import transport costs.

[7] The government module could be easily modified to add any number of service sectors or ministry-type accounts, addressing urban investment costs, rural investment costs and recurrent costs. The simulations presented in this paper include four illustrative sectors – health, education, infrastructure, and public administration – in addition to road building and maintenance. Labor costs are determined by staff numbers and the relative wage, which is in turn determined by service sector wages. Imported commodity inputs can also be easily specified to a particular year.

[8] Road building helps to mitigate inflation among staple food as a primary consumption good that is affected by transport costs, but it does not play a major role in determining nonfood price indexes in an economy with no intermediate goods.

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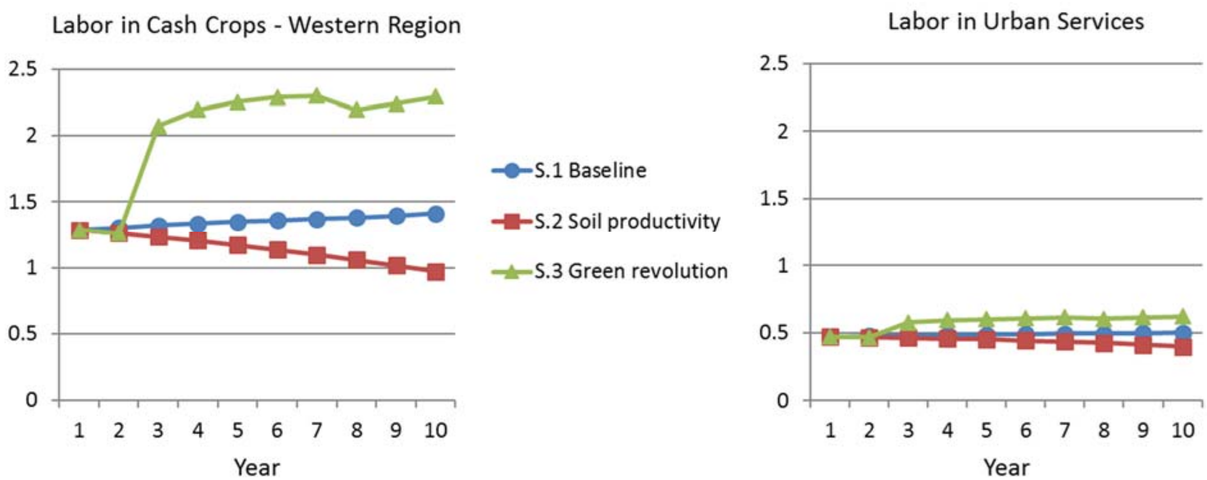
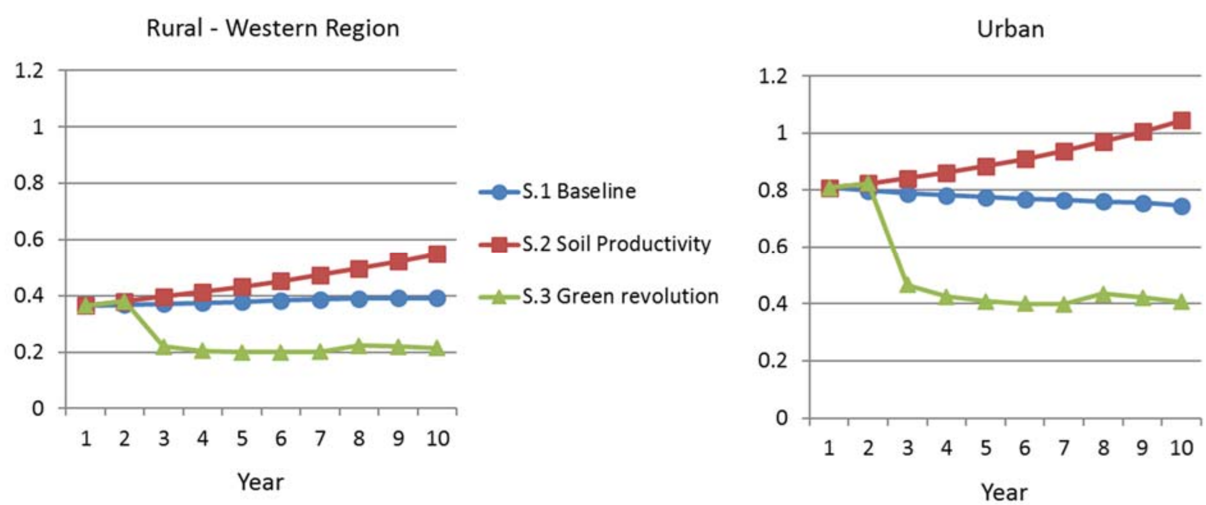
Figure 1: Sectoral labor shifts



Note: S.1 = scenario 1; S.2 = scenario 2; S.3 = scenario 3

Source: Authors' calculations.

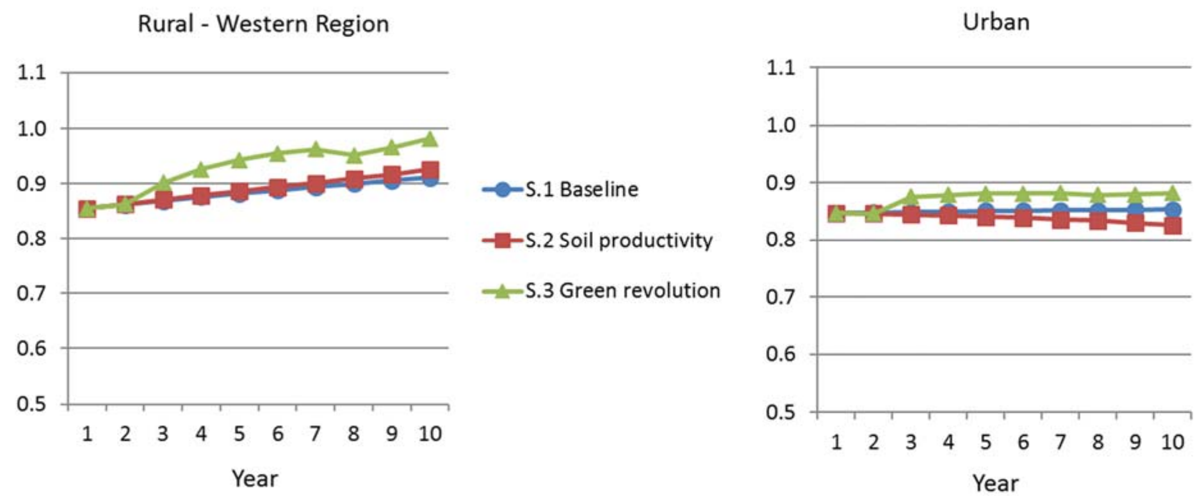
Figure 2: Food price



Note: S.1 = scenario 1; S.2 = scenario 2; S.3 = scenario 3

Source: Authors' calculations.

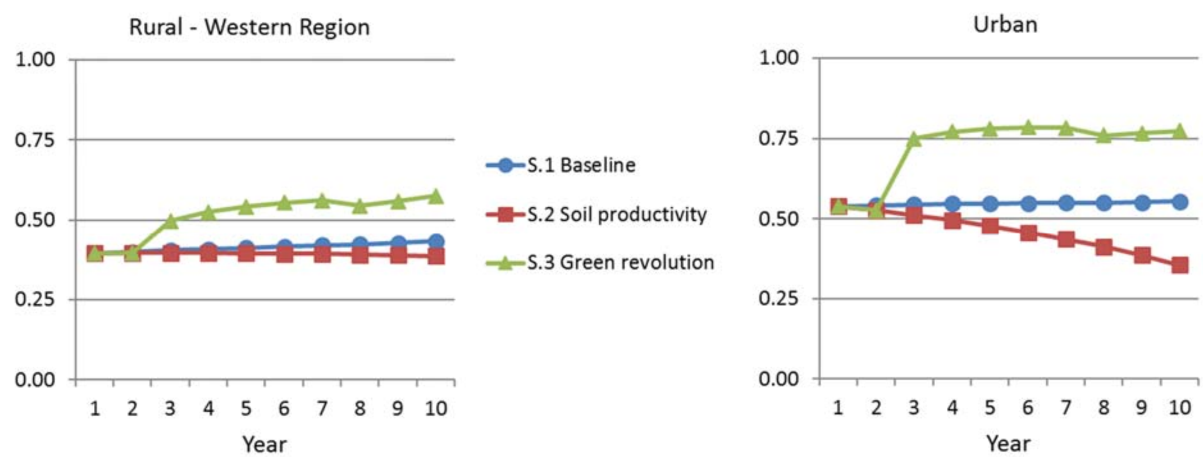
Figure 3: Non-food Consumer Price Index



Note: S.1 = scenario 1; S.2 = scenario 2; S.3 = scenario 3

Source: Authors' calculations.

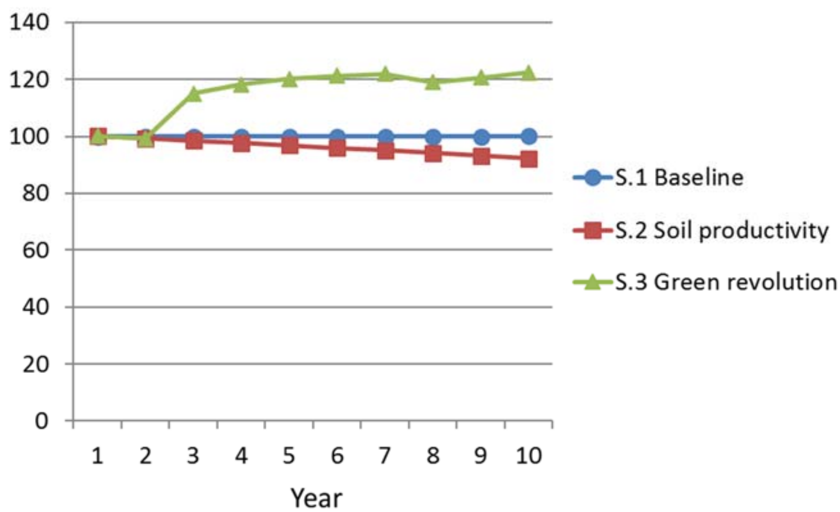
Figure 4: Real wage



Note: S.1 = scenario 1; S.2 = scenario 2; S.3 = scenario 3

Source: Authors' calculations.

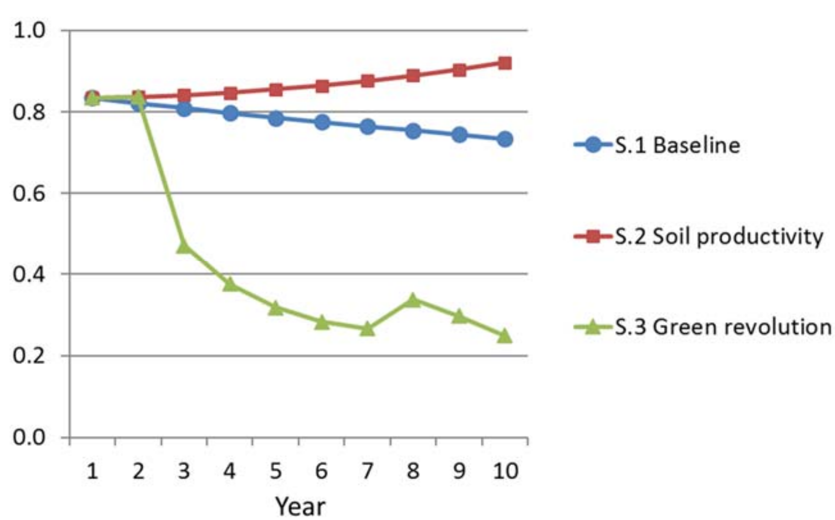
Figure 5: Total private output – real index (year 1 = 100)



Note: S.1 = scenario 1; S.2 = scenario 2; S.3 = scenario 3

Source: Authors' calculations.

Figure 6: Budge support ODA



Note: S.1 = scenario 1; S.2 = scenario 2; S.3 = scenario 3

Source: Authors' calculations.

Table 1: Geographic indexing of productive sector activity

Sector	Price (T/NT)	Rural Regions				Urban Region
		Western	Eastern	Northern	Central	Kampala
Staple food	NT	√	√	√	√	
Cash crops	T	√	√	√	√	
Rural service	NT	√	√	√	√	
Urban service	NT					√
Manufacturing	T					√
Imported capital & consumption goods	T	√	√	√	√	√

Note: T = tradable; NT = nontradable.

Source: Authors

Table 2: Geographic indexing of public sector activities

	Rural Regions				Urban Region
	Western	Eastern	Northern	Central	Kampala
Agriculture (Green Revolution package)	√	√	√	√	
Roads	√	√	√	√	
Other services	√	√	√	√	√
Administration					√

Source: Authors

Table 3: Mapping of key model components, by scenario

	Scenario		
	1	2	3
Key Model Component	Baseline	Soil Productivity	Green Revolution
Soil productivity term in agricultural production functions		√	√
Green Revolution input package introduced in years 3-7			√

Source: Authors

Table 4: Key results from scenarios

	S.1 - Baseline			S.2 - Soil Productivity			S.3 - Green Revolution		
	Time Period			Time Period			Time Period		
	1	5	10	1	5	10	1	5	10
SOIL PRODUCTIVITY									
- Western region *(index)*	1.00	1.00	1.00	1.00	0.96	0.90	1.00	1.14	1.29
AGRICULTURAL INPUTS									
- Total rural use *(index)*	-	-	0.01	-	-	-	-	0.82	0.35
LABOR *(MM workers)*									
Food									
- Western region	2.34	2.26	2.18	2.34	2.49	2.75	2.34	1.15	1.09
- Total rural	9.43	9.15	8.86	9.43	9.98	10.94	9.43	4.88	4.72
Cash Crop									
- Western region	1.29	1.35	1.41	1.29	1.17	0.97	1.29	2.26	2.29
- Total rural	4.57	4.79	5.01	4.57	4.14	3.40	4.57	8.22	8.34
Rural Service									
- Western region	0.77	0.78	0.78	0.77	0.73	0.67	0.77	0.98	0.98
- Total rural	2.88	2.90	2.93	2.88	2.73	2.48	2.88	3.72	3.69
Urban									
- Service	0.47	0.49	0.50	0.47	0.45	0.40	0.47	0.60	0.62
- Manufacturing	1.81	1.83	1.86	1.81	1.86	1.93	1.81	1.73	1.78
MIGRATION *(MM workers)*									
- Total rural to urban	0.01	0.01	0.01	0.01	0.01	-	0.01	0.02	0.01
PRICES									
- Rural food (Western)	0.36	0.38	0.39	0.36	0.43	0.55	0.36	0.20	0.21
- Urban food	0.81	0.78	0.75	0.81	0.88	1.05	0.81	0.41	0.41
- Rural NCPI (Western)	0.86	0.88	0.91	0.86	0.89	0.93	0.86	0.94	0.98
- Urban NCPI	0.85	0.85	0.85	0.85	0.84	0.83	0.85	0.88	0.88
REAL WAGE									
- Rural service (Western)	0.40	0.41	0.43	0.40	0.40	0.39	0.40	0.54	0.58
- Urban service	0.54	0.55	0.55	0.54	0.48	0.36	0.54	0.78	0.77

(…cont)

Table 4: (cont.)

	S.1 - Baseline			S.2 - Soil Productivity			S.3 - Green Revolution		
	Time Period			Time Period			Time Period		
	1	5	10	1	5	10	1	5	10
SAVINGS									
- Gross national rate (%)	11.0	11.2	11.4	11.0	10.3	9.1	11.0	15.1	14.9
CAPITAL									
- Cash crop (Western)	5.00	5.06	5.20	5.00	5.05	5.12	5.00	5.19	5.75
- Rural service (Western)	5.00	4.85	4.73	5.00	4.84	4.68	5.00	4.94	5.10
- Urban service	10.00	9.69	9.38	10.00	9.67	9.20	10.00	9.81	9.80
- Manufacturing	10.00	9.79	9.59	10.00	9.76	9.40	10.00	9.90	10.00
GOVERNMENT									
- Total expenditure	2.09	2.11	2.13	2.09	2.12	2.16	2.09	2.13	2.15
- Tax revenues	1.26	1.32	1.40	1.26	1.26	1.24	1.26	1.81	1.90
EXTERNAL									
- Exports	5.24	5.53	5.84	5.24	5.24	5.07	5.24	7.73	8.46
- Imports	6.10	6.34	6.60	6.10	6.12	6.02	6.10	8.87	8.73
- FDI	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.02	0.03
AID *									
- Cash ODA	0.84	0.79	0.73	0.84	0.86	0.92	0.84	0.32	0.25
- Green revolution ODA	-	-	-	-	-	-	-	0.80	-
TOTAL PRIVATE OUTPUT									
- Real index (Year 1 = 100)	100.0	99.9	100.1	100.0	96.8	92.2	100.0	120.1	122.4

Note: prices are in domestic terms relative to a fixed nominal exchange rate and numeraire tradable prices. FDI = foreign direct investment; NCPI = non-food consumer price index; ODA = official development assistance.
Source: Authors' calculations.

Table 5: Key details for Scenario 3 – Green Revolution

	Time Period									
	1	2	3	4	5	6	7	8	9	10
SOIL PRODUCTIVITY										
- Western region *(index)*	1.00	0.99	0.98	1.07	1.14	1.19	1.23	1.26	1.28	1.29
AGRICULTURAL INPUTS										
- Total rural use *(index)*	0.00	0.00	1.20	1.00	0.82	0.68	0.55	0.22	0.28	0.35
LABOR *(MM workers)*										
Food										
- Western	2.34	2.37	1.37	1.22	1.15	1.10	1.09	1.21	1.15	1.09
- Total rural	9.43	9.55	5.77	5.17	4.88	4.72	4.67	5.17	4.95	4.72
Cash Crop										
- Western	1.29	1.26	2.07	2.20	2.26	2.29	2.30	2.20	2.24	2.29
- Total rural	4.57	4.48	7.51	8.00	8.22	8.36	8.39	7.98	8.15	8.34
Rural Service										
- Western	0.77	0.76	0.95	0.97	0.98	0.99	0.99	0.96	0.97	0.98
- Total rural	2.88	2.85	3.58	3.68	3.72	3.74	3.73	3.63	3.66	3.69
Urban										
- Service	0.47	0.47	0.58	0.59	0.60	0.61	0.61	0.60	0.61	0.62
- Manufacturing	1.81	1.82	1.72	1.72	1.73	1.74	1.75	1.77	1.78	1.78
PRICES										
- Rural food (Western)	0.36	0.38	0.22	0.20	0.20	0.20	0.20	0.22	0.22	0.21
- Urban food	0.81	0.82	0.47	0.43	0.41	0.40	0.40	0.44	0.42	0.41
- Rural NCPI (Western)	0.86	0.86	0.90	0.93	0.94	0.96	0.96	0.95	0.97	0.98
- Urban NCPI	0.85	0.85	0.88	0.88	0.88	0.88	0.88	0.88	0.88	0.88
REAL WAGE										
- Rural service (Western)	0.40	0.40	0.50	0.53	0.54	0.55	0.56	0.55	0.56	0.58
- Urban service	0.54	0.53	0.75	0.77	0.78	0.78	0.78	0.76	0.77	0.77
SAVINGS										
- Gross national rate (%)	11.0	10.8	14.4	14.9	15.1	15.2	15.1	14.6	14.7	14.9
GOVERNMENT										
- Total expenditure	2.09	2.10	2.10	2.12	2.13	2.14	2.14	2.14	2.14	2.15
- Tax revenues	1.26	1.26	1.63	1.74	1.81	1.85	1.88	1.80	1.85	1.90
ODA										
- Cash ODA	0.84	0.84	0.47	0.38	0.32	0.28	0.27	0.34	0.30	0.25
- Green revolution ODA	0.00	0.00	1.20	1.00	0.80	0.60	0.40	0.00	0.00	0.00
TOTAL PRIVATE OUTPUT										
- Real index (Year 1 = 100)	100.0	99.2	114.9	118.3	120.1	121.3	121.9	119.0	120.5	122.4

Note: prices are in domestic terms relative to a fixed nominal exchange rate and numeraire tradable prices. FDI = foreign direct investment; NCPI = non-food consumer price index; ODA = official development assistance.
Source: Authors' calculations.

Supplemental Appendix to

"Agriculture, Aid and Economic Growth in Africa"

by John W. McArthur and Jeffrey D. Sachs.

Appendix S1: Model Equation Listing

BLOCK 1: AGRICULTURAL PRODUCTION FUNCTIONS

(EQ.1.1) $F_{i,t} = S_{i,t} * thetaf_i * land_i * (1 + INPUT_{i,t}) * LF_{i,t}^{alphaf} * kf_i^{betaf}$

(EQ.1.2) $VF_{i,t} = F_{i,t} * PFR_{i,t}$

(EQ.1.3) $CC_{i,t} = S_{i,t} * thetacc_i * land_i * (1 + INPUT_{i,t}) * LCC_{i,t}^{alphacc} * (kcscale * KCC_{i,t})^{betacc}$

(EQ.1.4) $VCC_{i,t} = CC_{i,t} * PCCR_{i,t}$

(EQ.1.5) $$S_{i,t} = \frac{uppersoil_i}{1 + rho * EXPNUT_{i,t}}$$

(EQ.1.6) $EXPNUT_{i,t} = e^{-NUTSUM_{i,t}}$

(EQ.1.7) $NUTSUM_{i,t+1} = NUTSUM_{i,t} + NETIN_{i,t}$

(EQ.1.8) $NUTSUM_{i,t0} = nutrient0_i$

(EQ.1.9) $NETIN_{i,t} = INPUT_{i,t} – nlossrate$

(EQ.1.10) $INPUT_{i,t} = min(1, max(0, (kcscale * (KCC_{i,t} – ((1 + khurdle) * kcc0_i)))) + greenoda_t)$

BLOCK 2: NONAGRICULTURAL PRODUCTION FUNCTIONS

(EQ.2.1) $M_t = thetam_t * LM_t^{alpham} * (kmscale * KM_t)^{1-alpham}$

(EQ.2.2) $SU_t = thetasu_t * LSU_t^{alphas} * (ksscale * KSU_t)^{1-alphas}$

(EQ.2.3) $VSU_t = SU_t * PSU_t$

(EQ.2.4) $SR_{i,t} = thetasr_i * LSR_{i,t}^{alphas} * (ksscale * KSR_{i,t})^{1-alphas}$

(EQ.2.5) $VSR_{i,t} = SR_{i,t} * PSR_{i,t}$

BLOCK 3: FOOD MARKET CLEARANCE

(EQ.3.1) $FKAMP_t = phi * LU_t$

(EQ.3.2) $FKAMP_t = \sum_i FSURP_{i,t} * (1 - TLOSS_{i,t})$

(EQ.3.3) $FSURP_{i,t} = F_{i,t} - phi * LR_{i,t}$

BLOCK 4: TRANSPORT COSTS & PRICES

(EQ.4.1) $TLOSS_{i,t} = \frac{tlossfirst0_i}{kroadscale*KROAD_{i,t}}$

(EQ.4.2) $PFR_{i,t} = PFU_t*(1-TLOSS_{i,t})$

(EQ.4.3) $PCCR_{i,t} = 1-TLOSS_{i,t}$

(EQ.4.4) $CPINFU_t = PSU_t*gammas + pimpu_t*(1-gammas)$

(EQ.4.5) $CPINFR_{i,t} = PSR_{i,t}*gammas + pimpr_t*(1-gammas)$

BLOCK 5: LABOR INCOME BY SECTOR

(EQ.5.1) $WMAN_t = thetam_t*alpham*(kmscale*KM_t/LM_t)^{1-alpham}$

(EQ.5.2) $WSU_t = PSU_t*thetasu_t*alphas*(ksscale*KSU_t/LSU_t)^{1-alphas}$

(EQ.5.3) $WSR_{i,t} = PSR_{i,t}*alphas*thetasr_i*(ksscale*KSR_{i,t}/LSR_{i,t})^{1-alphas}$

(EQ.5.4) $MPF_{i,t} = \frac{PFR_{i,t} * F_{i,t} * alphaf}{LF_{i,t}}$

(EQ.5.5) $MPCC_{i,t} = \frac{PCCR_{i,t} * CC_{i,t} * alphacc}{LCC_{i,t}}$

(EQ.5.6) $WGR_{i,t} = pwageprem*WSR_{i,t}$

(EQ.5.7) $WGU_t = pwageprem*WSU_t$

(EQ.5.8) $MPCC_{i,t} = MPF_{i,t}$

(EQ.5.9) $RWMAN_t = \frac{WMAN_t - phi * PFU_t}{CPINFU_t}$

(EQ.5.10) $RWSU_t = \frac{WSU_t - phi * PFU_t}{CPINFU_t}$

(EQ.5.11) $RWSR_{i,t} = \frac{WSR_{i,t} - phi * PFR_{i,t}}{CPINFR_{i,t}}$

(EQ.5.12) $YFARM_{i,t} = \frac{VF_{i,t} + VCC_{i,t} - phi * PFR_{i,t} * LFARM_{i,t} - (INPUT_{i,t} - greenoda_t)}{CPINFR_{i,t} * LFARM_{i,t}}$

(EQ.5.13) $RWGOVU_t = \frac{WGU_t - phi * PFU_t}{CPINFU_t}$

(EQ.5.14) $RWGOVR_{i,t} = \frac{WGR_{i,t} - phi * PFR_{i,t}}{CPINFR_{i,t}}$

BLOCK 6: LABOR MIGRATION AND MARKET EQUILIBRIUM

(EQ.6.1) $RWSU_t = RWMAN_t$

(EQ.6.2) $RWSR_{i,t} = YFARM_{i,t}$

(EQ.6.3) $MIGRATE_{i,t} = migtheta*(RWSU_t - RWSR_{i,t})$

(EQ.6.4) $LR_{i,t+1} = LR_{i,t} - MIGRATE_{i,t}$

(EQ.6.5) $LR_{i,t0} = lr0_i$

(EQ.6.6) $LR_{i,t} = LFARM_{i,t} + LSR_{i,t} + LGR_{i,t}$

(EQ.6.7) $LFARM_{i,t} = LF_{i,t} + LCC_{i,t}$

(EQ.6.8) $LU_t = LM_t + LSU_t + LGU_t$

(EQ.6.9) $LU_t = \sum_i pop_i - \sum_i LR_{i,t}$

(EQ.6.10) $LG_t = \sum_i LGR_{i,t} + LGU_t$

(EQ.6.11) $LTOT_t = \sum_i LR_{i,t} + LU_t$

BLOCK 7: DISPOSABLE INCOME, TAXATION, CONSUMPTION AND SAVING

(EQ.7.1) $YU_t = (VSU_t+M_t+ GOVWU_t - phi*PFU_t*LU_t)*(1-taxr)$

(EQ.7.2) $YR_{i,t} =(VF_{i,t}+VCC_{i,t}+VSR_{i,t}+ GOVWR_{i,t} - (INPUT_{i,t} - greenoda_t) - phi*PFR_{i,t}*LR_{i,t})*(1-taxr)$

(EQ.7.3) $YRTOT_t = \sum_i YR_{i,t}$

(EQ.7.4) $YDIS_t = YU_t + \sum_i YR_{i,t}$

(EQ.7.5) $SAVU_t = max(0, (YU_t - (CPINFU_t*cmin*LU_t))*savurb)$

(EQ.7.6) $SAVR_{i,t} = max(0, (YR_{i,t} - (CPINFR_{i,t}*cmin*LR_{i,t}))*savrur)$

(EQ.7.7) $SAVTOT_t = SAVU_t + \sum_i SAVR_{i,t}$

(EQ.7.8) $CU_t = YU_t-SAVU_t$

(EQ.7.9) $CR_{i,t} = YR_{i,t}-SAVR_{i,t}$

(EQ.7.10) $SU_t = \frac{gammas*CU_t}{PSU_t}$

(EQ.7.11) $SR_{i,t} = \frac{gammas*CR_{i,t}}{PSR_{i,t}}$

BLOCK 8: TRADE BALANCE

(EQ.8.1) $IMPUC_t = (1\text{-}gammas)*CU_t$

(EQ.8.2) $IMPRC_{i,t} = (1\text{-}gammas)*CR_{i,t}$

(EQ.8.3) $IMPUI_t = SAVU_t + FDI_t$

(EQ.8.4) $IMPRI_{i,t} = SAVR_{i,t}$

(EQ.8.5) $EXPORT_t = \sum_i (CC_{i,t} * (1 - TLOSS_{i,t})) + M_t$

(EQ.8.6) $$IMPORT_t = \sum_i INPUT_{i,t} + \sum_i IMPRC_{i,t} + IMPUC_t + \sum_i IMPRI_{i,t} + IMPUI_t$$

$$+PUBINV_t + ROADINV_t + TOTIMPG_t$$

(EQ.8.7) $TB_t = EXPORT_t - IMPORT_t$

BLOCK 9: INVESTMENT AND CAPITAL ACCUMULATION

(EQ.9.1) $FDI_t = max(0, fdimult*(R_t - rworld))$

(EQ.9.2) $R_t = \dfrac{(1 - alpham) * M_t}{KM_t}$

(EQ.9.3) $KCC_{i,t+1} = KCC_{i,t}*(1\text{-}depcc) + rsavcc*SAVR_{i,t}$

(EQ.9.4) $KM_{t+1} = KM_t*(1\text{-}dep) + FDI_t + usavm*SAVU_t$

(EQ.9.5) $KCC_{i,t0} = kcc0_i$

(EQ.9.6) $KM_{t0} = km0$

(EQ.9.7) $KSU_{t0} = ksu0$

(EQ.9.8) $KSR_{i,t0} = ksr0_i$

(EQ.9.9) $KSU_{t+1} = KSU_t*(1\text{-}dep) + (1\text{-}usavm) *SAVU_t$

(EQ.9.10) $KSR_{i,t+1} = KSR_{i,t}*(1\text{-}dep) + (1\text{-}rsavcc)*SAVR_{i,t}$

BLOCK 10: PUBLIC SECTOR

a) Public balances

(EQ.10.1) $TAX_t = (VSU_t+M_t+ GOVWU_t - phi*PFU_t*LU_t)*taxr$

$+ \sum_i (VF_{i,t}+VCC_{i,t}+VSR_{i,t}+ GOVWR_{i,t} – (INPUT_{i,t}–greenoda_t) - phi*PFR_{i,t}* LR_{i,t})*taxr$

(EQ.10.2) $TOTEXP_t = TAX_t + CASHODA_t$

(EQ.10.3) $CODA = \sum_t CASHODA_t$

(EQ.10.4) $TOTEXP_t = \sum_p PEXP_{p,t} + ROADCOST_t$

(EQ.10.5) $PEXP_{p,t} = invu_{p,t} + \sum_i invr_{p,i,t} + RECCOST_{p,t}$

(EQ.10.6) $PUBINV_t = \sum_p invu_{p,t} + \sum_p \sum_i invr_{p,i,t}$

b) Roads

(EQ.10.7) $KROAD_{i,t+1} = KROAD_{i,t}*(1-dep) + invroad_{i,t}$

(EQ.10.8) $KROAD_{i,t0} = road0_i$

(EQ.10.9) $LROAD_{i,t} = invroad_{i,t}*klroad_i + maintlabor*KROAD_{i,t}$

(EQ.10.10) $ROADWAGE_{i,t} = LROAD_{i,t}*WGR_{i,t}$

(EQ.10.11) $ROADINV_t = \sum_i invroad_{i,t}$

(EQ.10.12) $ROADCOST_t = ROADINV_t + \sum_i ROADWAGE_{i,t}$

c) Other Public Capital Equations

(EQ.10.13) $KPU_{p, t+1} = KPU_{p,t}*(1-dep) + invu_{p,t}$

(EQ.10.14) $KPR_{p, i, t+1} = KPR_{p,i,t}*(1-dep) + invr_{p,i,t}$

(EQ.10.15) $KPU_{p, t0} = kpu0_p$

(EQ.10.16) $KPR_{p, i, t0} = kpr0_{i,p}$

d) Public Service Recurrent Expenditures

(EQ.10.17) $RECCOST_{p,t} = \sum_{reg} commod_{p, reg, t} + LABCOST_{p,t}$

(EQ.10.18) $LABCOST_{p,t} = lpu_{p,t}*WGU_t + \sum_i (lpr_{p,i,t}*WGR_{i,t})$

(EQ.10.19) $LGU_t = \sum_p lpu_{p,t}$

(EQ.10.20) $LGR_{i,t} = \sum_p lpr_{p,i,t} + LROAD_{i,t}$

(EQ.10.21) $GOVWU_t = WGU_t * LGU_t$

(EQ.10.22) $GOVWR_{i,t} = WGR_{i,t} * LGR_{i,t}$

(EQ.10.23) $GOVWRUR_t = \sum_i GOVWR_{i,t}$

(EQ.10.24) $GWBILL_t = GOVWU_t * GOVWRUR_t$

e) Public Service Import Content

(EQ.10.25) $TOTIMPG_t = \sum_p IMPG_{p,t}$

(EQ.10.26) $IMPG_{p,t} = \sum_{reg} (impcontc_p * commod_{p, reg, t})$

BLOCK 11: ECONOMIC AGGREGATES

(EQ.11.1) $FTOT_t = \sum_i F_{i,t}$

(EQ.11.2) $VFTOT_t = \sum_i VF_{i,t}$

(EQ.11.3) $VCCTOT_t = \sum_i VCC_{i,t}$

(EQ.11.4) $VSRTOT_t = \sum_i VSR_{i,t}$

(EQ.11.5) $GNPWF_t = VSU_t + M_t + VFTOT_t + VCCTOT_t + VSRTOT_t + GWBILL_t$

(EQ.11.6) $SAVGNPWF_t = \dfrac{SAVTOT_t}{GNPWF_t}$

Appendix S2: List of Variables in Model

Positive variables:

$CC_{i,t}$	Cash crop output
$CPINFU_t$	Nonfood consumer price index urban
$CPINFR_{i,t}$	Nonfood consumer price index rural
$CR_{i,t}$	Rural consumption
CU_t	Urban consumption
$EXPNUT_{i,t}$	Exponential of nutrient stock
$EXPORT_t$	Total exports
$EXTRACT_{i,t}$	Crop extraction of nutrients
$F_{i,t}$	Food output
FDI_t	Foreign direct investment
$FSURP_{i,t}$	Food surplus by region
$FTOT_t$	Total food production
GNP_t	National output value
$GOVWR_{i,t}$	Rural government wage bill in region i
$GOVWRUR_t$	Total rural government wage bill
$GOVWU_t$	Urban government wage bill
$GWBILL_t$	Totalgovernment wage bill
$IMPORT_t$	Total imports
$INPUT_{i,t}$	Modern agricultural input use
$KCC_{i,t}$	Capital in cash crop production
KM_t	Capital in manufacturing
$KPR_{p,i,t}$	Rural capital stock in sector in period
$KPU_{p,t}$	Urban capital stock in sector in period
$KROAD_{i,t}$	Road length
$KSR_{i,t}$	Capital in rural service
KSU_t	Capital in urban service
$LABCOST_{p,t}$	Public labor force cost in sector p
$LCC_{i,t}$	Labor in cash crop production
$LF_{i,t}$	Labor in food production
$LFARM_{i,t}$	Farm labor
LG_t	Total government labor
$LGR_{i,t}$	Rural government labor
LGU_t	Urban government labor
LM_t	Labor in manufacturing
$LR_{i,t}$	Labor in rural area
$LROAD_{i,t}$	Rural road building labor
$LSR_{i,t}$	Rural services labor
LSU_t	Urban services labor
LU_t	Labor in urban sector
M_t	Manufacturing output
$MPCC_{i,t}$	Marginal product of labor in cash crop production
$MPF_{i,t}$	Marginal product of labor in food production
$PCCR_{i,t}$	Price of cash crop in rural region
$PFR_{i,t}$	Price of food in rural region

PFU_t Price of food in urban region
$PSR_{i,t}$ Price of services in rural region
PSU_t Price of services in urban region

R_t Marginal product of capital in manufacturing
$RWSR_{i,t}$ Real wage in rural services net of food
$RWSU_t$ Real wage in urban services net of food

$S_{i,t}$ Soil productivity factor
$SR_{i,t}$ Rural services output
SU_t Urban services output

$TLOSS_{i,t}$ Transport losses

$VCC_{i,t}$ Value added of cash crop production in region
$VCCTOT_t$ Value added of total cash crop production
$VF_{i,t}$ Value of food production in region
$VFTOT_t$ Total value of food production
$VSR_{i,t}$ Value of rural service production
$VSRTOT_t$ Total value of rural service production
VSU_t Value of urban service production

$WCC_{i,t}$ Cash crop wage
$WGR_{i,t}$ Rural government salary
WGU_t Urban government salary
$WMAN_t$ Manufacturing wage
$WSR_{i,t}$ Rural service wage
WSU_t Urban service wage

$YFARM_{i,t}$ Real farm income
$YR_{i,t}$ Rural income in region
$YRTOT_t$ Total rural income

Free variables:

$CASHODA_t$ Cash ODA (non-agricultural budget support)
$CODA_t$ Cumulative cash ODA

$DISYRU_{i,t}$ Rural income in excess of minimum consumption (*cmin*)
$DISYUR_t$ Urban income in excess of minimum consumption (*cmin*)

$FKAMP_t$ Food need in Kampala

$GNPWF_t$ GNP with food

$IMPG_{p,t}$ Import content in public service sector expenditures
$IMPUC_t$ Urban consumer good imports
$IMPRC_{i,t}$ Rural consumer good imports
$IMPUI_t$ Urban investment good imports
$IMPRI_{i,t}$ Rural investment good imports

$MIGRATE_{i,t}$ Rural to Urban migration from region *i*

$NETIN_{i,t}$ Nutrient flow
$NUTSUM_{i,t}$ Indexed accumulation of nutrient flows

$PEXP_{p,t}$	Public service expenditures in sector *p*
$PUBINV_t$	Total public investment
$RECCOST_{p,t}$	Recurrent public service expenditures in sector
$ROADCOST_t$	Total road investment and maintenance cost
$ROADINV_t$	Total road investment cost across regions
$ROADWAGE_{i,t}$	Road building wage across regions
$RWGOVR_{i,t}$	Real wage in rural government net of food
$RWGOVU_t$	Real wage in urban government net of food
$RWMAN_t$	Real wage manufacturing sector net of food
$SAVGNPWF_t$	Total saving as a share of GNP with food
$SAVR_{i,t}$	Rural gross saving in region
$SAVTOT_t$	Total gross saving
$SAVU_t$	Urban gross saving
TAX_t	Total tax revenues
TB_t	Trade balance
$TOTEXP_t$	Total expenditures across sectors in each period
$TOTIMPG_t$	Total government public service sector imports
$YDIS_t$	Disposable income (total population)
$YGOVR_{i,t}$	Real rural public sector wage net of food

Appendix S3: Model Parameters

This paper focuses on the presentation of a general economic model rather than precise point estimates. Future research could usefully identify more refined subnational parameter values for Uganda. The parameters used for this model are presented below, and are set to a general baseline of the year 2002. Factor shares in production functions are assumed at standard values (e.g., see Eberhardt 2006). The cost of capital, depreciation rates, the FDI multiplier, share of services in consumption, and public sector service wage premiums are assumed. Capital stocks and productivity terms were estimated using the Uganda social accounting matrix for 2002 (Alarcon et al. 2006), and then scaled. Public sector import contents were set at one for simplicity.

The labor force is set to match the approximate reality of 19.6 million workers as of 2002, and the population of origin from each region matches the approximate real distribution of populations. The distribution of roads and agricultural capital stocks across the four regions provides another approximate match of the reality in Uganda. The Northern region is poorest, and therefore starts the first period with slightly higher transport losses, lower cash crop capital stock, and lower cash crop productivity.

Sets:

i	Rural regions [east, west, central, north]
p	Public service sectors [health, education, general infrastructure, public administration]
reg	Geographic divisions [east, west, central, north, kampala]
t	Time periods [T=10]

Scalars:

Label	Description	Value
alphacc	labor share in cash crop production	0.4
alphaf	labor share in food production	0.5
alpham	labor share in manufacturing production	0.7
alphas	labor share in services	0.7
betacc	capital share in cash crop production	0.3
betaf	capital share in food production	0.2
cmin	minimum nonfood consumption	0.1
dep	depreciation	0.03
depcc	cash crop depreciation	0.03
fdimult	multiplier for FDI	0.1
gammas	share of services in the disposable income basket	0.5
km0	initial capital in manufacturing	10
ksu0	initial capital in urban services	10
kcscale	scaling parameter on CC capital stock	0.2
khurdle	hurdle parameter on household CC constraint	0.03
kmscale	scaling parameter on M capital stock	0.2
kroadscale	scaling parameter on road stock	0.25
ksscale	scaling parameter on SR capital stock	0.2
maintlabor	road maintenance labor-capital ratio	0.005
migtheta	rural-urban income migration parameter	0.015
nlossrate	nutrient loss rate in soil	0.03
phi	food requirement per person	0.55
pwageprem	public sector service wage premium	1.2
rho	logistic function parameter	1.5
rworld	world cost of capital	0.1
rsavcc	share of rural saving to cash crop	0.6
savurb	urban saving rate out of disposable income	0.3
savrur	rural saving rate out of disposable income	0.25
taxr	tax rate on disposable income	0.15
usavm	share of urban saving to manufacturing	0.5

Parameters:

(A) Scenario-based

$greenoda_t$	ODA for Green Revolution Package
Scenario 1, 2:	$greenoda_t = 0$
Scenario 3:	{t=1, 0; t=2, 0; t=3, 0.3; t=4, 0.25; t=5, 0.2; t=6, 0.15; t=7, 0.1; t=8, 0; t=9, 0; t=10, 0}

(B) General

$impcontc_p$ Import content share in commodities for public sector p
$impcontc_p = 1$

$impcontk_p$ Import content share in capital for public sector p
$impcontk_p = 1$

$ltot_t$ Total labor
$ltot_t = 19.6$

$pimpr_t$ Price of imported goods in rural area
$pimpr_t = 1$

$pimpu_t$ Price of imported goods in urban area
$pimpu_t = 1$

(C) Regional

$commod_{p,reg,t}$ Commodity expenditures in sector *p* in period *t*
$commod_{p,reg,t} = 0.01$

$invroad_{i,t}$ Investment in rural road *i* in period *t*
$invroad_{i,t} = 0.2$

$invr_{p,i,t}$ Rural public investment in sector *p* in period *t*
$invr_{p,i,t} = 0.04$

$invu_{p,t}$ Urban public investment in sector *p* in period *t*
$invu_{p,t} = 0.04$

$kcc0_i$ Initial capital in cash crops
{east 5, west 5, north 4, central 6}

kf_i Capital in food production
{east 5, west 6, north 5, central 4}

$ksr0_i$ Initial capital in rural services
{east 5, west 5, north 5, central 5}

$klroad_i$ K-L ratio for road building
{east 0.02, west 0.02, north 0.02, central 0.02}

$kpu0_p$ Initial urban government capital stock in sector p
{health 1, educ 1, infr 1, padmin 1}

$kpr0_{i,p}$ Initial rural capital stock in region i and sector p
$kpr0_{i,p} = 0.1$

$land_i$ Land area in each rural region
{east 1.45, west 1.45, north 1.45, central 1.45}

$lpr_{p,i,t}$ Rural labor in public sector *p* in period *t*
$lpr_{p,i,t} = 0.02$

$lpu_{p,t}$ Urban labor in public sector *p* in period *t*
$lpu_{p,t} = 0.005$

$lr0_i$ Initial rural labor
{east 4.5, west 4.5, north 3.8, central 4.5}

$nutrient0_i$ Initial soil nutrient value
{east 1, west 1, north 1, central 1}

pop_i Population of origin from each region
{east 5.21, west 5.17, north 4.11, central 5.11}

$road0_i$ Initial road value
{east 4, west 4, north 4, central 4}

$tlossfirst_i$ Transport loss parameter
{east 0.5, west 0.55, north 0.6, central 0.45}

$thetacc_i$ Cash crop sector productivity term
{east 1, west 1.1, north 0.8, central 1}

$thetaf_i$ Food sector productivity term
{east 1, west 1, north 1, central 1}

$thetam_t$ Manufacturing productivity (urban only)
$thetam_t = 1.25$

$thetasr_i$ Rural service productivity
{east 1, west 1, north 1, central 1}

$thetasu_t$ Urban service productivity:
$thetasu_t = 1.2$

$uppersoil_i$ Upper soil productivity threshold
{east 1.552, west 1.552, north 1.552, central 1.552}

Appendix S4: Overview of Uganda as Illustrative African economy

Uganda faces many core challenges common across low-income African subsistence economies. Some key characteristics are described here. These draw from a range of sources, mainly published during the course of the early 2000s, and thus present a thematic overview rather than a precise snapshot at a single point in time. The data also predate Uganda's recent commencement of oil production.

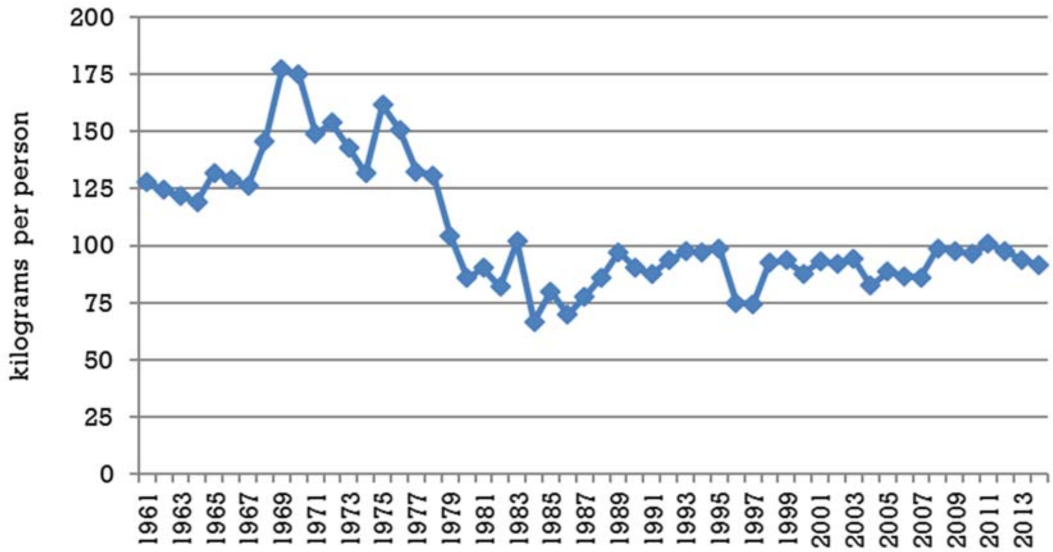
As of 2012, approximately 35 percent of Uganda's population still lived below the international extreme poverty line of $1.90 per day in 2011 purchasing power parity terms (World Bank 2017). The vast majority of the country's poverty is concentrated in rural areas, where most Ugandans are engaged in crop agriculture. Infrastructure is limited. Only approximately 10 percent of households had electricity as of the early 2000s (Okidi et al. 2005). For decades, gross domestic saving rates were extremely low, well below 10 percent of GDP, although they averaged a slightly higher 13.1 percent from 2006-2015 (World Bank 2017). A 1997 Bank of Uganda survey found that fewer than a quarter of rural Ugandans had ever saved and that 85 percent of the other three-quarters cited low income as the primary factor for not doing so (Musinguzi and Smith 2000).

i. Staple Food Agriculture

Uganda's staple agriculture sector has experienced general long-term stagnation. Figure S4.1 presents trend data for cereal production per capita from 1961 to 2014. From a peak of nearly 180 kilograms per person in 1969, output has been stagnant, at less than 100 kilograms per person, since the early 1980s. Figure S4.2 indicates similar trends for a broader index of food production per capita.

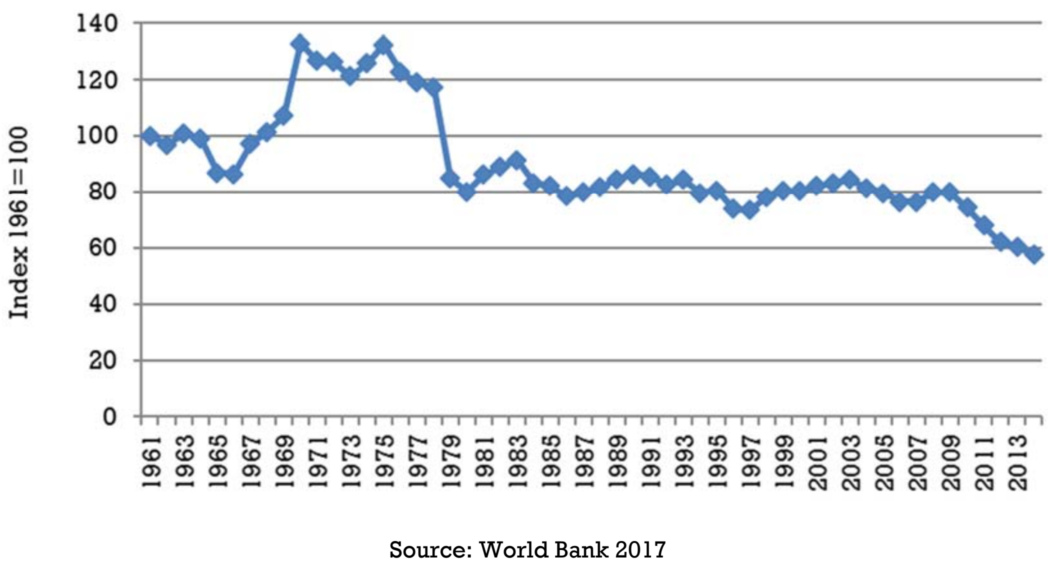
Siriri, Bekunda and Jama (2005) find that yields are typically one-quarter to one-tenth of current potential. This is significantly driven by the low usage of modern farm inputs. Fewer than a third of agricultural households use improved seeds, and only 8 percent use inorganic fertilizer (Okoboi and Barungi 2012). Yet despite the stagnation, Uganda has not become a marked food importer. Historically the country has engaged in almost no staple crop trade; for many years nearly all its imported food was wheat and maize aid for conflict-affected areas in the north.

Figure S4.1:
Uganda cereal production per capita, 1961-2014



Source: World Bank 2017

Figure S4.2:
Uganda Food Production per capita, 1961-2014

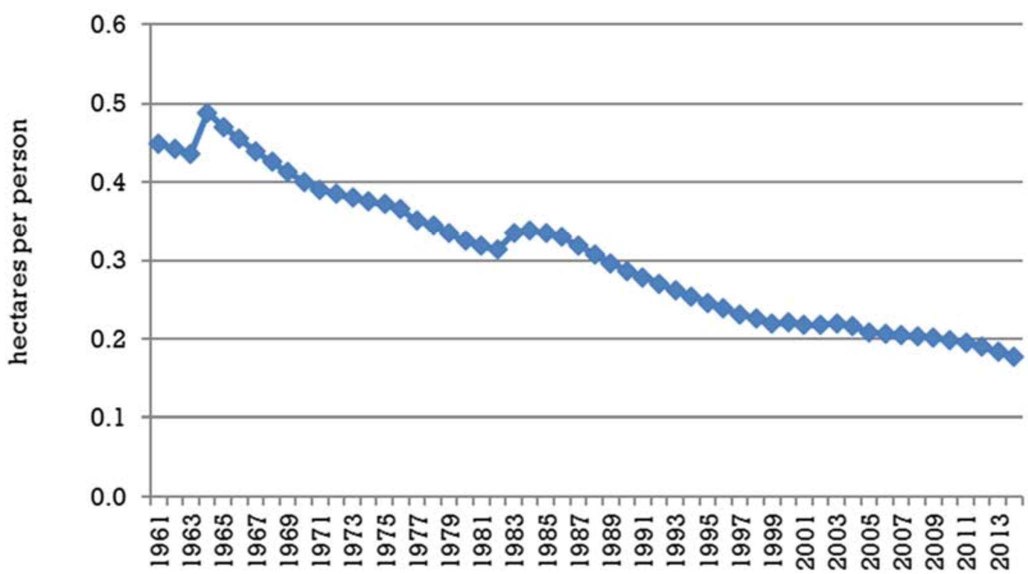


Source: World Bank 2017

ii. Soil Nutrients

Like much of Africa, Uganda faces a major soil nutrient challenge. For many years, agricultural output was maintained through land clearing, but population pressures (see Figure S4.3) and a lack of fallowing mean that farmers are now mining nutrients at faster rates and decreasing long-term yields in the process. Data compiled by Ssali (2002) and Ruecker (2005) indicate that a large portion of Uganda's soil is now below the so-called critical 3 percent value for soil organic matter. Henao and Baanante (2006) estimate loss rates for nitrogen, phosphorous and potassium to be among the highest in Africa, at more than 60 kilograms per hectare per year. The consequences are significant. Nkonya and colleagues (2005) estimate a cost of approximately $153 per household per year to replenish mined soil nutrients at market prices, equivalent to nearly a fifth of GDP at the time of calculation.

Figure S4.3:
Uganda arable land per person, 1961-2014



Source: World Bank 2017

Fallow periods have fallen from 10 to 15 years a century ago down to 2 and even zero years today (Nandwa and Bekunda 1998). In large parts of the country, fewer than 10 percent of farms have been estimated even to use fallows (Pender et al. 2001). Fertilizer is necessary, even if not sufficient, to stop and reverse the patterns of nutrient decline and address the soil nutrient challenge. However, cost is a barrier because staple crop farmers often face poor relative returns on fertilizer, often with a "value to cost ratio" of 1 or less (e.g., Wortmann and Kaizzi 1998; de Jager et al. 2003; Kaizzi 2002; Matsumoto and Yamano 2009).

Uganda's internal geographic heterogeneity underscores the disparate range of farming systems across Africa. Ruecker and colleagues (2003) identified seven categories of agricultural potential across the country based on permutations of four climate variables. First, annual precipitation cycles affect the extent of water availability throughout the year. The northeastern section of the country has unimodal rainfall, while the southern and central areas, which are closer to the equator, have bimodal rainfall. Second, the length of growing period is measured as the period over which mean monthly rainfall exceeds half the mean potential evapotranspiration. This ranges from less than 5 months in the northeastern districts to 10 or more months in the central region and in the southwestern highlands. Third, the actual level of annual precipitation varies tremendously throughout the country and changes at a steep gradient, particularly in the "crescent" around Lake Victoria. Fourth, extreme temperatures constrain agricultural productivity. The range of growing conditions results in significant variations in the concentration of staple crop by region.

iii. Other Key Sectors

Cash crops, especially coffee, have historically been a major driver of Uganda's growth and poverty reduction. However, fewer than 10 percent of the country's farm households grow coffee, and the commodity's share of exports has declined significantly (Kappel et al. 2005; Bussolo et al. 2006). As of the mid-2000s, cotton, tea and tobacco had increased in volume and total value exported, while flower exports had also been introduced. Fisheries have overtaken coffee in overall export value, but only a small share of the population is engaged in that activity. In any case, all the export shares need to be considered in the context of Uganda's low overall export/GDP ratio, which ranged between 15-24 percent from 2006-2015 (World Bank 2017).

Manufacturing remains a small element of the economy, historically accounting for less than 10 percent of GDP, as indicated in Table A1. Table A2 shows that the sector still employed less than 4 percent of the labor force as of 2002. The service sectors—including wholesale and retail trade, transport, communications and construction—employed approximately 9 percent of the labor force, split fairly evenly between urban and rural areas, accounting for approximately one-third of GDP. Government accounted for the largest share of GDP, at approximately 20 percent, and 7 percent of the labor force. Most of the public labor force is situated in rural areas where the population lives, but approximately one-third is based in urban areas, especially the public administration hub of Kampala.

TABLE S4.1

Uganda GDP Sector Shares, 1990/91 - 2004/05

MONETARY SECTORS	1990/91	1994/95	1999/00	2004/05
Agriculture	22.7%	25.2%	20.3%	18.7%
- Cash crops	2.8%	6.3%	3.6%	2.8%
- Food crops	12.3%	12.2%	10.7%	10.2%
- Livestock	4.1%	3.4%	3.4%	2.7%
- Forestry	1.1%	0.9%	0.7%	0.7%
- Fishing	2.4%	2.3%	2.0%	2.3%
Mining & quarrying	0.3%	0.3%	0.8%	0.9%
Manufacturing	5.7%	7.2%	9.4%	9.0%
Electricity/water	0.9%	1.3%	1.4%	1.3%
Construction	4.8%	5.5%	7.6%	9.3%
Wholesale & Retail Trade	12.3%	12.0%	11.2%	10.9%
Hotels & Restaurants	1.3%	1.8%	2.4%	3.3%
Transport/communication	4.0%	3.9%	5.3%	7.7%
- Road	2.9%	3.0%	3.7%	3.5%
- Rail	0.3%	0.2%	0.2%	0.1%
- Air & Support. Services	0.4%	0.4%	0.5%	0.5%
- Communications	0.4%	0.4%	0.9%	3.6%
Community services	15.4%	17.0%	20.4%	20.0%
- General government	3.2%	4.5%	4.3%	4.2%
- Education	3.9%	4.0%	6.1%	6.4%
- Health	1.5%	1.3%	2.2%	2.3%
- Rents	3.2%	3.5%	4.3%	3.8%
- Miscellaneous	3.6%	3.8%	3.6%	3.2%
TOTAL MONETARY	67.4%	74.1%	78.7%	81.0%
NON-MONETARY SECTORS				
Agriculture	28.4%	22.3%	16.9%	14.8%
- Food crops	25.7%	19.9%	13.7%	11.9%
- Livestock	1.3%	1.2%	1.9%	1.7%
- Forestry	1.1%	0.9%	1.2%	1.0%
- Fishing	0.3%	0.3%	0.3%	0.3%
Construction	0.8%	0.7%	0.6%	0.5%
Owner-occupied Dwelling	3.3%	2.9%	3.7%	3.7%
TOTAL NON-MONETARY	32.6%	25.9%	21.3%	19.0%

Sources: Uganda Ministry of Finance, Planning and Economic Development 2005; authors' calculations.

TABLE S4.2

Sectoral Decomposition of Ugandan Labor Force and Value Added, 2002

Sector	Rural labor	% of national labor force	Urban labor	% of national labor force	Total labor	% of national labor force	% of Net Value Added
Staples and Cash Crops	4,796,824	69.0%	115,768	1.7%	4,912,592	70.7%	18.3%
Animal farming	260,581	3.7%	22,298	0.3%	282,879	4.1%	2.1%
Mining and Quarrying	14,616	0.2%	5,124	0.1%	19,740	0.3%	0.3%
Tradable Manufacturing	208,296	3.0%	64,737	0.9%	273,033	3.9%	10.6%
Utilities	5,508	0.1%	8,861	0.1%	14,369	0.2%	3.9%
Non-tradable local capital goods	58,774	0.8%	49,934	0.7%	108,708	1.6%	11.6%
Non-tradable services	190,815	2.7%	222,521	3.2%	413,336	5.9%	28.4%
Tradable services	105,806	1.5%	117,219	1.7%	223,025	3.2%	8.1%
Public service	317,228	4.6%	188,741	2.7%	505,969	7.3%	16.7%
Other	99,193	1.4%	97,193	1.4%	196,386	2.8%	
Totals	**6,057,641**	**87.2%**	**892,396**	**12.8%**	**6,950,037**	**100.0%**	**100.0%**

Sources: Uganda Bureau of Statistics 2004; Alarcon et al. 2006; authors' calculations.

iv. Transport Costs and Infrastructure

A key attribute of Uganda’s economy is its limited infrastructure and high transport costs, which are among the highest in the world (Buys 2006). In multiple sectors, including food, these costs provide both implicit protection for domestic producers and implicit taxation on exports (Milner et al. 2000; Rudaheranwa 2006). Poor roads are responsible for much of the high costs. The 2005 National Transport Plan reported only 5 percent of the country’s roads as paved, and only approximately 40 percent of those in good condition (Uganda Ministry of Works, Housing, and Communications and TAHAL Engineers 2005).

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