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A Consistent Food Demand Framework for International Food Security Assessment

John Beghin, Birgit Meade, and Stacey Rosen

Selected Paper prepared for presentation at the International Agricultural Trade Research Consortium's (IATRC's) 2014 Annual Meeting: Food, Resources and Conflict, December 7-9, 2014, San Diego, CA.

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A Consistent Food Demand Framework for International Food Security Assessment

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Abstract: A parsimonious demand modeling approach has been developed for the annual USDA-ERS *International Food Security Assessment*. The approach incorporates price effects, food quality variation across income deciles, and consistent aggregation over income deciles and food qualities. The approach is based on a simple PIGLOG demand approach for four food categories. It relies on the existing sparse data available for the assessment, complemented by own-price and income elasticities and available price data. Beyond exact aggregation, the framework exhibits desirable characteristics: food quality is increasing with income; price and income responses become less sensitive with increasing income; and increasing income inequality decreases average per capita food consumption. The proposed approach is illustrated for Tanzania. We then use the calibrated model to decompose the impact of income, prices, and exchange rates on food consumption.

Keywords: international food security, PIGLOG demand, aggregation, income inequality, food prices, shocks

JEL codes: F17, Q17, D31

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1. Introduction

This paper proposes a systematic approach to introduce prices, food quality heterogeneity, and consistent aggregation over income decile consumption into the economic model currently used by USDA's Economic Research Service in its annual *International Food Security Assessment*. The *Assessment* projects food consumption per decile for 76 low- and middle-income countries for the forthcoming decade. This paper derives a food demand system for four categories of foods covered by the *Assessment* and by income decile.

The approach is based on the PIGLOG demand approach in a basic formulation. This paper explains how to consistently aggregate decile food demands into average consumption per capita as a function of average income and a correction factor exhausting all the information on income distribution across population deciles. For each food category, the proposed approach explicitly incorporates a measure of the decile income distribution and provides exact aggregation of decile demands into a market average demand for that category as explained below.

Further, the approach allows for variable quality of food items, with quality increasing with increasing income. Various qualities of a given food category are aggregated into an average-quality equivalent that leaves country-level data unchanged, reflecting what happens in the real world. Wealthier consumers upgrade the quality of good they buy relative to poorer consumers. Prices faced by different deciles vary accordingly with quality. Lower-income deciles consume cheaper calories than higher-income deciles do. Within each good category, consumption of heterogeneous qualities can be aggregated over decile in "average-quality" equivalent units. Domestic and world markets are connected. Domestic and world prices are linked through synthetic transmission equations including tariffs, real exchange rates, transportation, and other trade costs.

This paper further explains how to calibrate the demands using the limited information typically available for the annual *Assessment*, namely average per capita consumption, data on income and income projections, recent income distribution data, to which we add incomplete data on domestic prices, data on and projections for international prices, and sparse estimates of income and own-price elasticities available from USDA-ERS (Muhammad et al., 2011). Cross-price effects are ignored because of the scarcity of cross-price estimates. This paper focuses on Tanzania and the country's staple grain, corn. Appendix Excel files are available from the contact author. They present the detailed data and calibration of the price transmission equations and the demand system and for the four food categories (corn, other grain aggregate, roots and tubers (R&T), and aggregate all other foods) and with projections for 2013–2023.

The calibration optimizes the use of data and estimates generated by USDA, such as the macro database and macro projections maintained by ERS for real exchange rates, CPI, population and income, the estimated demand elasticities by Muhammad et al. (2011), and the international price projections of *USDA Agricultural Projections to 2023*. The model presented here also makes use of information on estimated food consumption from the Tanzania USDA model used in the 2013 *Assessment* (see USDA-ERS, 2013).

The aggregation over the four categories of goods considered in the food consumption balance (two grain categories, R&T, all-other-foods aggregate) is consistently incorporated in the approach with grains being further disaggregated into a major grain and all other grains. Price indices specific to each commodity group are proposed for within-group aggregation (e.g., all other grain prices into a grain price index). This is illustrated for grain consumption for Tanzania. We then explain how we include the variable quality of goods in the demand system and then how the new demand structure is incorporated into the existing food security assessment framework.

The remainder of the paper presents the consumer demand specification, followed by the aggregation to market demand, calibration, price transmission equations, quality scaling, demand decomposition, and concluding comments.

2. Specification of consumer demand

The motivation for using the PIGLOG specification (Muellbauer 1975; Lewbel 1989) is that it is a general specification well grounded in micro-economic foundations. It allows for an exact aggregation of demand by the 10 deciles for each good category to an aggregate market demand. It also results in a specification of the average per capita aggregate demand expressed as a function of average per capita income and the Theil index of income inequality (Theil 1967) summarizing the income distribution over deciles (Muellbauer 1975). Finally, the PIGLOG specification easily exhibits shares of food expenditure that are decreasing with real income. This feature is a stylized fact of food consumption levels determined by income levels. The expenditure shares per good category can be summed-up and demands per category can be aggregated into calories or grain calorie equivalent over categories. In a first step for presentation purposes, we assume quality constant, and then later in the paper, the variable quality and prices using a scaling approach are introduced.

The specification of the PIGLOG expenditure share on good category i, w_i, is

$$w_i = A_i(p_i / P) + B_i(p_i / P)\ln(x / P), \qquad (1)$$

with variable x being the nominal income of the consumer, and with nominal price p_i and price index P for all other goods. Functions A and B are homogenous degree zero in nominal prices p_i and P. We normalize P to 1 without any loss of generality and rewrite the share as

$w_i = A_i(p_i) + B_i(p_i)\ln(x)$, with price and income variables being in real terms from now on.

Marshallian demand q_i is

$$q_i = (x / p_i)\left(A_i(p_i) + B_i(p_i)\ln(x) \right). \qquad (2)$$

We further specify $A_i(p_i)=a_{io} + a_{i1}\, p_i$, and $B_i(p_i)=b_{io}+b_{i1}\, p_i$. Other specifications are possible. This one is parsimonious and focuses on the own-price response. All other cross-price effects are subsumed in parameters a_{io} and b_{io}. When data and cross-price estimates are available, more elaborate responses can include cross-price effects in future refinements and elaborations.

The income elasticity of demand *i* is

$$\varepsilon_{q_i x} = 1 + (B_i(p_i) / w_i) = 1 + [(b_{io} + b_{i1} p_i) / w_i], \qquad (3)$$

which is decreasing in income if B_i is negative. Equation (3) accommodates normal or inferior goods and a range of elasticities over deciles as the share of expenditure w_i varies by decile.

The own-price elasticity is

$$\varepsilon_{q_i p_i} = -1 + (p_i / w_i)((b_{i1} \ln(x) + a_{i1}). \qquad (4)$$

Equation (4) also accommodates a range of elasticities by decile as income and share of expenditure vary by income decile. When calibrated appropriately, income elasticity (3) is decreasing with income. Similarly, the absolute value of price elasticity (4) can be calibrated to be decreasing with income. A free parameter in the calibration allows imposing such patterns as explained below in the calibration section (see Section 4).

3. Aggregating decile demands to the average aggregate demand for good *i*

The PIGLOG formulation allows for exact aggregation of decile-level demand for any good into the total market demand. It also results in an average per capita market demand expressed as a function of average income and Theil's entropy measure of income inequality among income classes (Muellbauer 1975). Here, we assume a distribution of income by population decile, which is the way USDA and many other agencies assess at-risk groups with respect to food insecurity (i.e., the lowest-income deciles being assessed).

Using superscript h to denote decile-specific variables with h=1,…,10, we have decile-level food demand as

$$q_i^h = (x^h / p_i)\left(A_i(p_i) + B_i(p_i)\ln(x^h)\right). \qquad (5)$$

Equation (5) leads to average per capita demand $\bar{q}_i$ by simple aggregation over deciles. The latter is a function of average per capita income $\bar{x}$ and Theil's entropy measure of income inequality z measured on the decile income distribution:

$$\bar{q}_i = (\bar{x} / p_i)\left(A_i(p_i) + B_i(p_i)(\ln(\bar{x}) + \ln(10/z))\right), \qquad (6)$$

with

$$\ln(10/z) = \ln(10) + \sum_{h=1}^{10}(x^h / X)\ln(x^h / X), \text{ and with } X = \sum_{h=1}^{10} x^h = 10\bar{x}. \qquad (7)$$

Entropy measure z reaches its maximum at 10 when all deciles have similar income. In this case ln(10/z) equals zero. Any income inequality leads to (10/z) > 1. Given some inequality and a negative value for $B_i(p_i)$, it can be seen that income inequality decreases the level of average consumption per capita for the corresponding good category. As shown in (6), abstracting from income inequality will overstate average demand relative to the average demand implied by the individual decile demands.

With our chosen specifications of $A_i(p)$ and $B_i(p)$ as defined previously, we can further express average demand for good i as

$$\bar{q}_i = (\bar{x} / p_i)\left((a_{io} + a_{i1}p_i) + (b_{io} + b_{i1}p_i)(\ln(\bar{x}) + \ln(10/z))\right). \qquad (8)$$

We also define average expenditure share for good category i as

$$\bar{w}_i = \left((a_{io} + a_{i1}p_i) + [(b_{io} + b_{i1}p_i)(\ln(\bar{x}) + \ln(10/z))]\right). \qquad (9)$$

The elasticity of average demand for good *i* with respect to average income is

$$\varepsilon_{\bar{q}_i \bar{x}} = 1 + (B_i(p_i)/\bar{w}_i) = 1 + [(b_{io} + b_{i1}p_i)/\bar{w}_i]. \qquad (10)$$

The own-price elasticity of the average demand is

$$\varepsilon_{\bar{q}_i p_i} = -1 + (p_i/\bar{w}_i)(b_{i1}(\ln(\bar{x}) + \ln(10/z)) + a_{i1}). \qquad (11)$$

All consumers in different deciles have similar underlying preferences over good *i* as embodied in parameters a_{io}, a_{i1}, b_{io}, b_{i1}, and their respective consumptions vary because their respective incomes vary.

4. Calibration for good *i*

Data on average consumption, average income, price, and decile income distribution are available from the Food Security database maintained by USDA-ERS. From the decile income distribution data, one can compute the Theil index (equation (7)). Using equations (9) through (11) for the average expenditure share and the two elasticities of average demand for good *i*, demand $\bar{q}_i$ can be calibrated. Then, individual decile demands q_i^h can be calibrated using the parameters recovered in the calibration of the average demand. The calibration uses the observed average expenditure shares of good *i*, an estimate of the two elasticities for the average demand, and a specified value of a free parameter as explained below.

With a system of three linear equations (equations (9)–(11)) with four unknown variables, one parameter remains free. The free parameter (chosen to be b_{io}) is used to insure that decile demands behave consistently with stylized facts of food security as follows. Price sensitivity and income responsiveness decline with income levels; own-price elasticities must be negative; and food expenditure shares tend to fall with increasing income. A range of values of the free parameters allows insuring these stylized facts are satisfied by the calibrated demand system.

For any given free parameter value, the system of equations is solved for parameters b_{i1}, a_{i1}, and a_{io} as a function of the free parameter. Once these three parameters are recovered, the decile demands and their corresponding elasticities are estimated based on the decile income levels and the aggregate elasticities. This step relies on the four parameters (one free parameter and three calibrated) and equation (2) with $A_i(p_i)=a_{io} + a_{i1}\, p_i$, and $B_i(p_i)=b_{io}+b_{i1}\, p_i$ for the demands and (3) and (4) for each decile elasticities.

The calibration is recursive. Four steps are involved:

1. Parameter b_{i1} is first recovered from the income elasticity estimate $\hat{\varepsilon}_{\bar{q}_i\bar{x}}$ and for a given value of $\hat{b}_{io}$, both denoted by hats, that is,

$$\hat{\varepsilon}_{\bar{q}_i\bar{x}} = 1 + (B_i(p_i)/\bar{w}_i) = 1 + [(\hat{b}_{io} + b_{i1}p_i)/\bar{w}_i],$$

leading to

$$\tilde{b}_{i1} = [\bar{w}_i(\hat{\varepsilon}_{\bar{q}_i\bar{x}} - 1) - \hat{b}_{io}]/p_i.$$

Tildes denote calibrated values.

2. Next, the calibrated value of the a_{i1} parameter is recovered, given calibrated parameter $\tilde{b}_{i1}$, an estimate of the own-price elasticity of the aggregate average demand for good i $\hat{\varepsilon}_{\bar{q}_i p_i}$, and the observed average income and Theil index z. The expression for the calibrated value of parameter a_{i1} is

$$\tilde{a}_{i1} = \bar{w}_i(\hat{\varepsilon}_{q_i p_i} + 1) - \tilde{b}_{i1}(\ln(\bar{x}) + \ln(10/z)).$$

3. The calibrated value of the last parameter a_{io} is recovered from the average share of expenditure (9),

$$\tilde{a}_{io} = \bar{w}_i - \left(\tilde{a}_{i1} p_i + (\hat{b}_{io} + \tilde{b}_{i1} p_i)(\ln(\bar{x}) + \ln(10/z))\right).$$

4. Parameters $\tilde{a}_{io}, \tilde{a}_{i1}, \hat{b}_{io}$, and $\tilde{b}_{i1}$, along with income x^h and price p_i are used to generate the consumption level of good *i* for each decile. Similarly one can compute the associated decile-specific elasticities of demand with respect to income and price using equations (2)–(4). Again, in this initial calibration, the quality of good *i* is assumed constant across deciles.

Step 4 completes the calibration and characterization of each decile's consumption of any given good *i*, and assuming that quality remains the same across all deciles. The four-step process illustrates the link between decile demand and aggregate market demand. It also demonstrates the correspondence between income and price responsiveness of the average and individual per-capita demands through exact aggregation over individual decile demand. In the context of the food security outlook, the same sequence of steps is undertaken for four categories of food in Tanzania (corn as the staple grain, other grains, R&T, and all-other-foods aggregate). An example of such calibration is provided in an appendix file along with the calibration for the four good types and the decile consumption in the base year of 2012. The four categories will be common to all potential study countries; but the staple grain will be country-specific, and the composition of "other grains," R&T, and "all other foods" will also be country specific.

Price index for aggregate category

Three of the goods (other grains, R&T, and aggregate all other foods) include several commodities. For goods with international and/or domestic price data available (i.e., grains), we use a weighted (by share of consumption) price index aggregating prices of various grains into a grain composite price index. For other products (R&T and all other foods), this approach does not appear sound, as nutritional content per unit of weight varies dramatically over goods (i.e., dairy, meat, oils, vegetables). Their aggregation is done on a grain-based equivalence.

For R&T, the international price of cassava is used as a representative world price and is linked to local prices of R&T such as yam or manioc from FAO GIEWS whenever available for 2012. All prices are in grain equivalent. The price of vegetable oil in grain equivalent is used as a representative price for “all other food.” This is not ideal, but oil tends to be an important component of other foods in most countries and its international price is readily available. Other “representative” commodities could be used.

Synthetic price transmission equations are used to link the world and domestic prices expressed in grain equivalent. These are explained in detail in the next section. The transmission equation includes tariffs and transportation costs from world markets to the domestic market as well as the effect of the real exchange rate. The indices of domestic prices are explained in detail in the appendix. The final price values and intercepts between world and domestic prices are then reproduced into the model file (see sheet called “DPs & WPs”) in the model file called “USDA model April 29.” To illustrate, the prices are shown in Table 1.

Aggregation over the four types of goods

Next, the aggregation of the four food types is considered to derive a calorie or grain equivalent to the estimated demands. The aggregation is feasible because the four food categories are expressed in calorie-equivalent as done in FAO’s food balance sheets and can be easily expressed in grain-equivalent (or any food item equivalence) from calorie-equivalent. Each food category is characterized by a grain or calorie energy intake per unit of consumption. Naturally, the 4 demands can be aggregated to a total grain or calorie equivalent, which in turn responds to price and income via the economics underlying each of the four food demand components (major grain, other grains, R&T, and all other foods). Table 2 shows the calibration for corn per decile for Tanzania.

5. Price transmission equation

Following the work of Mundlak and Larson (1992), Campa and Goldberg (2005) and others, the price transmission equation links the local real consumer price of good *i* to the corresponding world market price and embodies the influence of world prices, international transportation, exchange rates, trade policy, and other transaction costs arising from bringing commodities to local markets. Each real consumer price for any tradable importable commodity *i* is linked to the corresponding world market price as follows:

$$p_i = (ER\ (wp_i(1+trc_{\text{int}})(1+tariff) + trc_{\text{dom}}) / P, \qquad (12)$$

where *ER* is the nominal exchange rate in local currency units per U.S. dollar, wp_i is the FOB price of commodity *i*, *trc* denotes trade and transportation costs in the international market (*int* subscript) in ad valorem form and in the domestic market of the importing country in specific form (*dom* subscript); *tariff* denotes the sum of all specific and ad valorem tariffs imposed on the good and expressed in ad valorem form, and where *P* is the CPI deflator (or GDP deflator) in the importing country as defined previously. Trade and transportation costs can be commodity specific.

Note that (12) can equivalently by expressed with world price *wp* expressed as a real world price *rwp* (real constant US dollars/mt), real exchange rate *RER* (real local currency units (LCU) per real US dollar), and real trade costs *rtrc* other than tariffs and international transportation cost in real LCUs, and then not further deflating by the local CPI deflator *P*. This step yields:

$$p_i = (RER\ (rwp_i(1+trc_{\text{int}})(1+tariff)) + rtrc_{\text{dom}}). \qquad (12')$$

Other specifications than (12) or (12') are possible, especially if econometric estimates of price transmissions are available. An intercept can be added, or a slope coefficient to (12) to reflect the econometric estimates of a regression of the type (p = a + b wp). The additive form of (12) and (12') provides a price-transmission elasticity (dln$p$/dlnrwp), which is less than one by construction as long as some additive tariff or trade costs are present.

For the implementation of the price transmission equation, there are two cases: (*a*) both domestic and international prices are available, and an intercept (which subsumes all trade costs between world and domestic markets) can be derived to link the two prices expressed in similar real LCUs; or (*b*) only the international price is available and a synthetic domestic price is estimated using the price transmission described in (12). To compute (12), tariffs are obtained from the WTO website (WITS and/or Macmap databases are also alternatives); the CPI deflator P is available from the USDA-ERS macro database; FOB/CIF ratios are estimated at 1.10 in ad valorem form for importable goods and not accounted for in the case of exportable. Similarly tariffs are not included for exportables since the price signal at the margin is in the export market. Domestic trade costs are assumed to be $20 per metric ton of grain equivalent (2005 real prices). World price data are obtained from USDA's world outlook which allows making 10-year projections. These transmission equations are shown in table 1 with the implied intercept between world and domestic price expressed in similar real LCUs. See the excel file for further details.

6. Quality scaling

Consistent with real-world observation, it is assumed that the quality of good i increases with income and that its price is also increasing with quality. Therefore, low-income consumers consume cheaper quality purchased at a lower price and vise-versa for higher income consumers.

We posit that quality is represented by a scaling factor $\mu(x)$ which, when normalized, appropriately over all deciles is equal to 1. The scaling factor scales quality and prices down such that the product of quality-adjusted quantity consumed and prices remain constant (quantity adjusted for quality and price move in opposite directions such that the estimated expenditure share is invariant to quality.

Using equation (2) and a definition of the scaling factor μ we have a quantity consumed with variable quality for any good i and decile h

$$q^h_{i\,adj} = q^h_i / \mu^h_i = (x^h / \mu^h_i p_i)\left(A_i(p_i) + B_i(p_i)\ln(x^h)\right), \qquad (13)$$

with

$$\mu^h_i > 0 \ \forall h, \text{ and } \sum_{h=1}^{10} (q^h_i / \mu^h_i)/10 = \bar{q}_i. \qquad (14)$$

Low-income deciles consume goods of cheaper quality in greater abundance ($q^h_{iadj} \geq q^h_i$ with μ^h smaller than unity) and richer consumers do the opposite by consuming higher quality goods in smaller amount once expressed in quality-adjusted units ($q^h_{iadj} \leq q^h_i$ with μ^h larger than unity).

The scaling is calibrated such that on average over deciles, the mean of the variable-quality consumption levels is equal to the mean consumption per capita holding quality constant as expressed by equation (14). Expenditures are invariant to scaling since the price and quantity are inversely scaled and offset each other. One can think of consumption in average-quality equivalent (in equation (2) or in variable-quality units in equation (13)). To compute calorie availability (13) is used. To calibrate the demand system, equation (2) is used and then we impose the scaling on top of the original demand calibration. To do so, a reference consumption level is established in variable-quality units for the first (lowest) decile, which is represented by $q^1_{iadj\,\min}$ in equation (15) below. This level for the first decile can be based on additional sources of information from household surveys or other sources when these are available. It represents a credible level of consumption in grain equivalent for the poorest segment of the country.

The scaling parameter μ for good *i* and decile *h* is derived using the adjusted consumption level as follows:

$$q^h_{iadj\min} = (\alpha + \beta q^h_i), \text{ or}$$

$$\mu^h_i = q^h_i / (\alpha + \beta q^h_i), \qquad (15)$$

with

$$\beta = (\overline{q}_i - q^1_{iadj\min}) / (\overline{q}_i - q^1_i) \text{ and } \alpha = q^1_{iadj\min} - \beta q^1_i.$$

For the Tanzanian model illustration we use the 1st decile per capita consumption estimated by USDA in its *International Food Security Assessment, 2013-23*, that is, 207 kg of grain equivalent (rounded) per year in Tanzania. Each of the four goods contributes proportionally to the first decile's reference consumption level and each is scaled up to sum up to the aggregate reference consumption level. The constraint of having the mean quality equal to 1 over all deciles provides a second equation to illustrate how quality evolves over deciles. The demand-weighted-average scaling factor is equal to 1, such that the scaling does not "create" consumption in the aggregation over decile. The sum of all consumption over deciles with variable quality sums up to the same food volume estimated assuming constant average quality.

Over time, this minimum consumption in adjusted united is allowed to grow slowly with a limited response to rising income and rising consumption (see details in the Appendix). For example, for Tanzania, quality increases are included by scaling up each consumption for the four categories to achieve a minimum aggregate calorie intake of 1,855 calories per day for the lowest decile then deriving a proportional minimum consumption and scaling schedule for each of the 4 commodities (corn, other grains, R&T, all other foods) so that exact aggregation holds through. The 1855-calorie figure is equal to USDA's estimate of the lowest decile consumption in Tanzania for 2013 in its 2013 projections. The quality scaling for corn per decile is shown per decile in Table 2.

The scaling structure is illustrated in the Figure 1 for the four goods included in the Tanzanian model and for the base year. The figure shows how the scaling evolves as income changes, moving across deciles in any given year. Here, the figure was calibrated for the base data of 2012 as explained previously. Over time as income increases, the lowest decile's consumption grows with income.

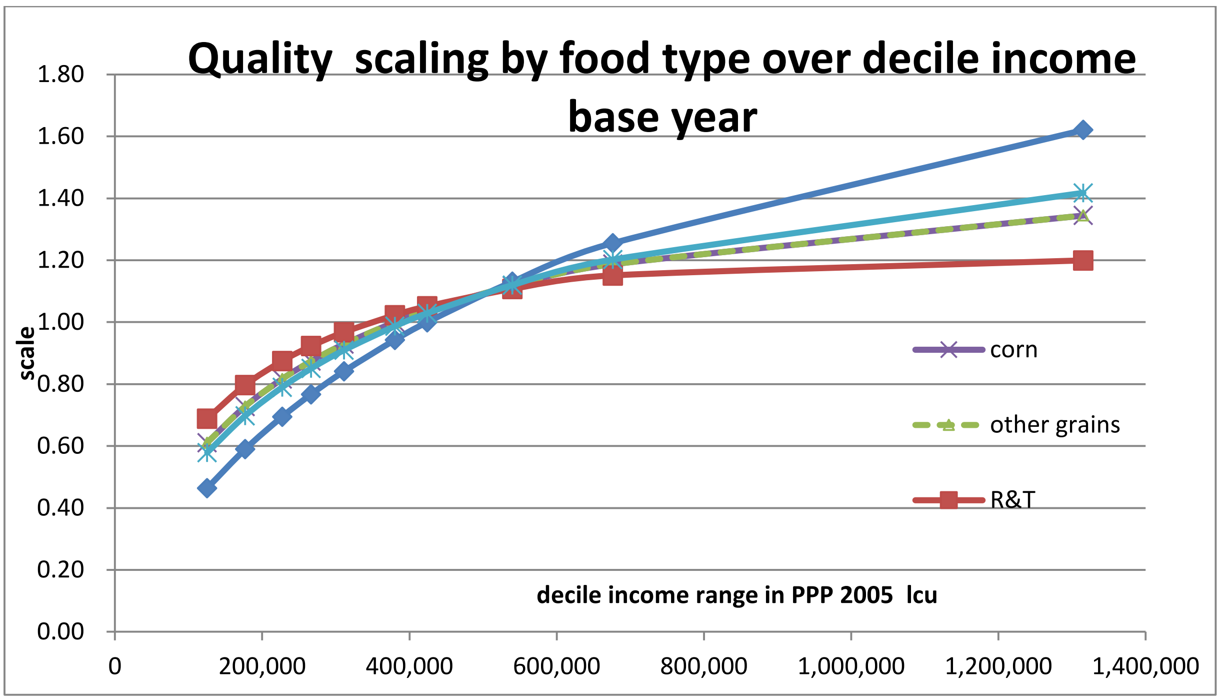

Figure 1

We let quality increase as well (the scaling factor slowly increases, but remains below 1 for the lowest income groups), which translates into a net increase in the lowest-decile consumption when quality is accounted for. Conversely, for deciles starting with above-average quality (scaling factors larger than 1 in the base year), as income progresses, quality adjustments relative to the mean quality eventually decrease. The range of quality differences across deciles shrinks over time as average income increases. This feature is a consequence of imposing the demand-weighted average quality equal to 1 in all years.

There is some intuition to this feature—quality dispersion decreases when everyone's income rises. Figure 2 illustrates this change in scaling for the 1st decile in the Tanzanian model. Other-food, which includes meats and dairy products, shows that larger adjustments persist (further away from 1) more than for R&T. R&T is the least income-responsive good among the four goods included in the demand system.

One drawback of the approach is that it does not account for average market quality increasing over time. As countries become more affluent over time, one would expect that, on aggregate, quality improves for most food items. Hence, the scaling proposed here is more a relative quality scaling rather than absolute since average quality remains equal to 1.

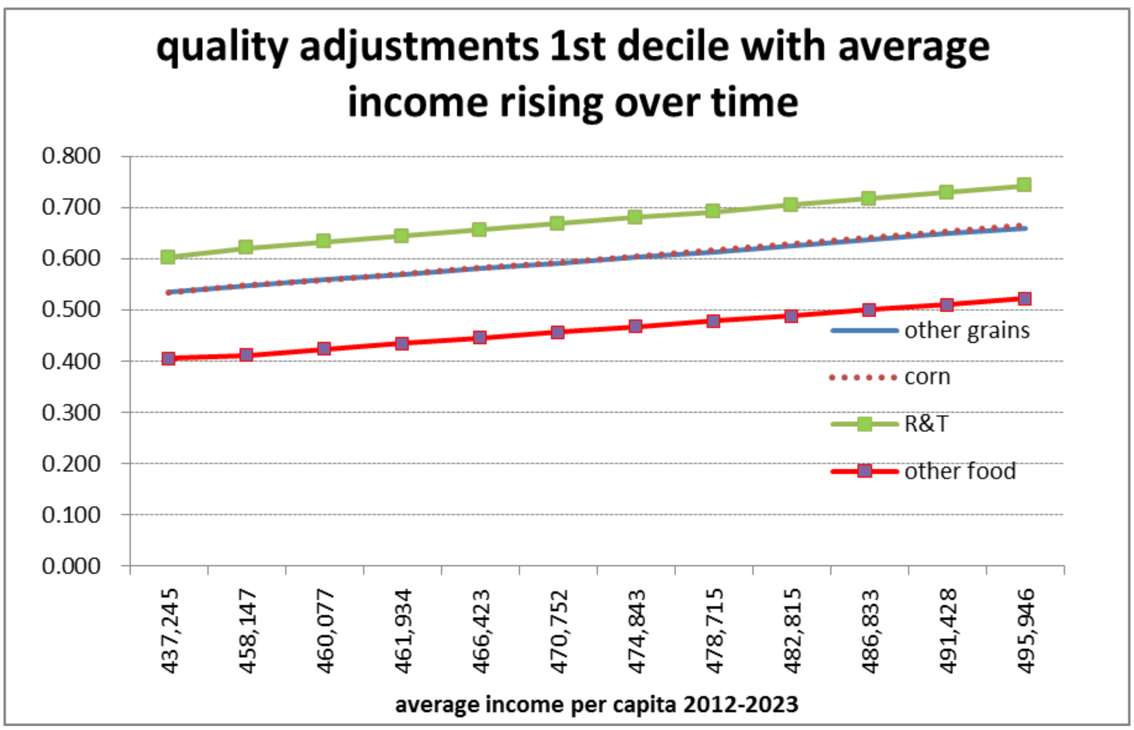

Figure 2.

7. Integrating the new demand approach in the *Assessment*

This section explains how the new demand system will be integrated into the current model used for the *Assessment*. The supply side of the model, which remains unchanged, is presented first. Then we explain the new closure of the model with residual trade under the small-country assumption.

7.1. Projection of food supply

The simulation framework used for projecting aggregate food supply is based on partial equilibrium recursive models of the low- and middle-income countries included in the *Assessment*. The country models are synthetic, meaning that the parameters that are used are either cross-country estimates or are estimated by other studies. Each country model includes historical production and use data on the two most important food categories, aggregate grains and R&T. The two grain categories used on the demand side will be aggregated back into a single grain category to match domestic supply and demand and determine imports residually. The disaggregation/re-aggregation of grains allows for better tracing potential price chocks into the consumption of the major grain which could impact food security, while keeping the supply side of the model relatively tractable for 76 countries.

Grains and R&T comprise the largest share of most countries' diets—up to 80 percent. However, to capture 100 percent of the countries' diets there is a third category "other foods," which represents all other consumed food products. "Other food" is obtained from FAOSTAT food balance sheets by subtracting grains and R&T consumption from each country's total calories consumption and is predicted exogenously. This calorie measure can then be expressed in grain equivalent, using each country's conversion rate based on its individual grain product consumption. All food commodities are converted into grain equivalent based on calorie content to allow aggregation. For example, grain has roughly 3.5 calories per gram and tubers have about

1 calorie per gram. One MT of tubers is therefore equivalent to 0.29 MT of grain (1 divided by 3.5), and 1 MT of vegetable oil (8 calories per gram) is equivalent to 2.29 tons of grain (8 divided by 3.5)**.**

Production of grains and R&T are each projected for a 10–year period and are determined by the area and yield response functions:

$$PR_{cnt} = AR_{cnt} * YL_{cnt}, \qquad (16a)$$

$$YL_{cnt} = f\,(LB_{cnt}, FR_{cnt}, K_{cnt}, T_{cnt}), \qquad (16b)$$

$$RPY_{cnt} = YL_{cnt} * DP_{cnt}, \qquad (16c)$$

$$RNPY_{cnt} = NYL_{cnt} * NDP_{cnt}, \qquad (16d)$$

$$AR_{cnt} = f\,(AR_{cnt-1}, RPY_{cnt-1}, RNPY_{cnt-1}, Z_{cnt}), \qquad (16e)$$

where *PR* is production, *AR* is area, *YL* is yield, *LB* is rural labor, *FR* is fertilizer use, *K* is an indicator of capital use, *T* is the indicator of technology change, *DP* is real domestic price, *RPY* is the real gross return per acre, *NDP* is real domestic substitute price, *NYL* is yield of substitute commodity, *RNPY* is the real gross return per acre for the substitute commodity, and *Z* represents exogenous policies. The equations are calculated for all countries *c* and two commodities *n* (grains and R&T).

The functional form chosen is a double-log equation. Crop area is a function of 1-year lag (t-1) real gross returns to crop production, lagged returns to substitute crops, and lagged crop area. Yield responds to input use: labor, fertilizer use, capital, and technology change.

To close each domestic market, excess demand clears on the world market. The world and domestic price levels are linked through transmission equations explained in section 5. Net trade is the residual that satisfies the difference between domestic production and food demand. For many of the countries studied here, production of grains and R&T falls short of demand, thus leading to food imports. Countries are assumed to be price takers in the international market, meaning that world prices are exogenous in the model.

7.2. Data for the supply side

Historical crop production, supply and use balance, and trade data up to the most recent available year (2012 or 2013 when available) are from FAOSTAT, FAO/GIEWS and USDA as of March 2014. Food aid data are from the UN's World Food Program (WFP) up to 2012. Population data are from the UN Population Division, 2012 Revision, medium variant. The base year data used for projections are the average for 2010–2012. A series of variables are assumed exogenous and projected outside the model including population, world prices, agricultural inventories, seed use (constant base seed/area ratio), fertilizer and capital projections, and agricultural labor.

7.3. Food Security Indicators of the International Food Security Model

Two food insecurity indicators are estimated for the current year as well as ten years out: the number of food insecure people and the distribution gap, explained below. Food security is generally defined in terms of four dimensions: food availability, food access, food utilization, and stability. No one analysis or indicator can address all four dimensions as they rely on very different types of information and data.

The USDA-ERS International Food Security Assessment Model estimates and projects food availability defined as food production plus/minus other uses—such as feed and seed use and stock changes—plus net trade. The main focus and contribution of the *Assessment* model, however, is its projection of food demand by income group, as described in detail in the preceding sections of this paper. This focus on individual income groups allows for the analysis of the access dimension of food security, which looks at the question of whether households have sufficient purchasing power to buy the food they need. For this purpose, we use the decile food demands, subject to income constraints and responding to price signals for the 10 income groups. This decile food demand is then compared with a nutritional target to determine whether a given income group would be considered food secure.

The nutritional target is based on a daily caloric intake standard of about 2,100 calories per capita per day. The caloric target is converted into grain equivalent quantities. This conversion is based on the calorie per gram relationship of grains and R&T, weighted by each country's diet composition shares. The consumption share of "other" food products is converted into grain equivalent based on the grain conversion rate.

If the estimated decile food demand falls below the target, the entire income group is counted as food insecure. Aggregating the people in these food-deficit income groups provides one of our food insecurity indicators—**the number of food-insecure people**. This indicator became a flagship measure in 1996 when 185 countries at the World Food Summit in Rome set the goal to reduce the number of food insecure people by half by 2015.

However, the number of food insecure people provides no indication of the depth of food insecurity. A given income group might be consuming just below the target level, allowing for food security improvements by slightly increasing access to food, either by income transfers or price policy. Another income group might be found to consume at half the target level, which would indicate severe food insecurity. To illustrate the depth of the food insecurity problem we also evaluate countries based on the gap between projected domestic food demand and the consumption target. We call this gap the **distribution gap**. The objective is to allow each income group to reach the nutritional target. If food demand based on incomes and prices in a given income group is lower than this target, that difference is part of the distribution gap for this country. The gaps for all income groups are added up to determine the distribution gap for a given country.

The distribution gap can be expressed as the total amount of food required to allow each income decile to reach the nutritional target, but it can also be expressed as a per capita gap, either in quantity or as a ratio, in percent of the target.

8. Decomposition of projected demand by its determinants

In this last section, a decomposition of the projected growth of demand is illustrated from 2012 to 2023 in terms of its determinants. Total demand growth is decomposed into per capita demand growth and population growth. Then, per capita demand growth is further decomposed in terms of the income response and the price response, which itself is decomposed into a real world price response and real exchange rate response. The growth of projected total demand is then approximated by linearization as in Dong, (2006), Heien and Wessells (1988), and Shui et al. (1993). The decomposition for infinitesimal changes is

$$d\ln(totQ_i(pop, rwp, RER, \bar{x}) = d\ln(pop) + d\ln(\bar{q}_i) = d\ln(pop) + \varepsilon_{\bar{q}_i p_i}\varepsilon_{p_i rwp_i}(d\ln(rwp) + \mathrm{d}\ln(RER)) + \varepsilon_{\bar{q}_i \bar{x}} d\ln(\bar{x})),$$

discretely approximated by

$$\frac{\Delta totQ_i}{totQ_i} \approx \left(\frac{\Delta pop}{pop} + 1\right)\left(1 + \varepsilon_{\bar{q}_i p_i}\varepsilon_{p_i rwp_i}\left(\frac{\Delta rwp}{rwp} + \frac{\Delta RER}{RER} + \frac{\Delta rwp}{rwp}\frac{\Delta RER}{RER}\right) + \varepsilon_{\bar{q}_i \bar{x}}\frac{\Delta \bar{x}}{\bar{x}}\right) - 1, \qquad (17)$$

with $totQ_i$ denoting total food demand for commodity *i*, *pop* denoting population of the country, and with $\varepsilon_{p_i rwp_i}$ being the price transmission elasticity. The growth rates (*Δx/x*)) are taken from 2012 to 2023. Note that second equation in (17) is an approximation since the elasticities are endogenous and vary with price, quantities, and income. The price transmission elasticity for corn in Tanzania is 0.785, evaluated for the price change at the border and then at the domestic consumer level, between 2012 and 2023. We compute the effects as follows. For the domestic price effect on per capita demand, we look at $\left(\frac{\bar{q}(p_{2023},\bar{x}_{2012})}{\bar{q}(p_{2012},\bar{x}_{2012})} - 1\right)$ with real domestic price *p(rwp, RER*) defined as in equation (12'). This effect is then allocated proportionally to the relative changes in the *RER* and *rwp* between 2012 and 2023. For the income effect on per capita demand, we look at $\left(\frac{\bar{q}(p_{2012},\bar{x}_{2023})}{\bar{q}(p_{2012},\bar{x}_{2012})} - 1\right)$.The sum of the two effects (domestic price and income) are then summed up to approximate the relative change in per capita demand induced by the price, exchange rate, and income changes.

The decomposition is shown in Table 3. Based on the calibrated demands, total food demand for corn in Tanzania is projected to roughly double (100.35%) in the projected decade given the trajectory of projected real income per capita (+18%), real world price for corn (-49%) real exchange rate (-22%), and population (+35%). Per capita demand is projected to grow by 48% based on the calibrated demand per capita (equation (8)). The interaction of population growth and that of per capita demand is responsible for 17% growth of total demand (100.35% = 35% + 48% + 17%). Again, the latter figures are obtained using the calibrated demand.

The decomposition of the demand growth per capita shows that the change in the real world price after being scaled by the own-price elasticity and the price transmission elasticity is the most important contributor to per capita demand growth (25% growth of per capita demand). The real appreciation of the Tanzanian currency, after proper scaling by elasticities, leads to 12% of per capita demand growth. Finally, income growth contributes 9% growth of per capita demand. The approximation of per capita demand growth is not perfect, of course, and misses 2% of projected growth of per capita demand (48% projected – 46% estimated via the linearization of the 3 effects(25+12+9=46). The unaccounted 2% come from interaction between price and income changes and from the linear approximation implied in equation (16). The latter shortfall is slightly accentuated in the total demand projection, which is about 2.56% of growth short of the projected change (100.35% versus 97.79%). Similar decompositions could be computed by decile for which an additional factor could be added, that is, the quality scaling and its evolution over time. Since the quality scaling is normalized to 1 for aggregate demand in every year, the growth of total food demand is invariant to quality scaling.

9. Summary and concluding remarks

This paper presented a parsimonious modeling approach to incorporate price effects, quality variation, and consistent aggregation over income classes and food qualities in a food demand system. The approach can be used to assess calorie intake per decile, to investigate income, price, and exchange rate shocks, and could be applied to improve USDA's *International Food Security Assessment* model.

The approach is based on a simple PIGLOG demand approach for four food categories (major grains, other grains, R&T, and an aggregate all other food). The approach relies on the existing sparse data available for these assessments, which is a desirable feature. The proposed approach was illustrated for Tanzania. Two tables in this note illustrate the calibration, which is then used to decompose the impact of changes in population, income, world price, and real exchange rate on food demand over the 2012–2023 projection period as shown in Table 3.

The approach makes use of various USDA-ERS data products (elasticities estimates, macro data, past food security assessments, and international price outlook) and provides value added to the portfolio of these products. The approach could also incorporate external information from household surveys to better determine calorie availability per decile. The latter remains a difficult task despite much effort to collect household food availability data.

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Table 1. Example of price transmissions in Tanzania and supporting data used for 2012

Price transmission in Tanzania (prices are per metric ton)							
		exportable/importable	**observed or synthetic**	**Domestic price in Real LCU in grain equivalent**	**International price in Real LCU in grain equivalent**	**International price location from USDA Commodity Outlook**	**Implied intercept (DP-WP)**
Major grain (maize)	Maize/corn	importable	obs	286404.76	224806.3	USDA	61598.471
All other grains	Rice	importable	obs	938911.3	465782.4	USDA Thailand	473128.923
	Wheat	importable	syn	355066.5	236093.9	USA hard red winter USDA	118972.562
	Sorghum	importable	syn	281787.72	214926.6	USA sorghum USDA	66861.109
	Millet	exportable	syn	230742.65	214926.6	US sorghum USDA	15816.040
	Barley	importable	syn	308988.08	213216.0	USDA Rouen barley price	95772.052
grain index price				592736.36	331954.5	computed	260781.850
R&T	Cassava	importable	syn	1663415.3	1198254.0	USDA: Internat. cassava	465161.295
Other food	soy oil	importable	syn	448442.82	357542.8	USDA: Soy oil	90900.026

RER	929.70
CPI us	117.56
CPI Tanzania	197.07
CIF/FOB	10%
Taxes: AHS wheat	0.31
Taxes: AHS Sorghum	0.13
Taxes: AHS Millet	0.25
Taxes: AHS Barley	0.25
Taxes: AHS Maize	0.33
Taxes: AHS Rice	0.29
Taxes: Soy oil	0.1
Taxes: Cassava	0.25

Table 2. Example of demand calibration and quality adjustment per income decile: corn demand in Tanzania

Data and parameters used to calibrate the PIGLOG demand 2012 base year	value	unit
average income data	444171.9	real lcu/ capita
average corn quantity consumed (data)	74.580	kg/capita
aggregate income elasticity (data)	0.563	unitless
aggregate price elasticity (data)	-0.413	unitless
consumer price major grain (data)	286.4048	real lcu/kg
Thiel index (ln(10/z)) computed from decile data	0.229018	unitless
average expenditure share (data)	0.04809	unitless
bo free parameter (set freely)	-0.013	
b1 (computed)	-2.7986E-05	
a1 (computed)	0.00047	
ao (computed)	0.19189	

decile	income shares by decile in %(data)	calibrated decile average demands kg per capita	computed decile income elasticities	computed decile price elasticities	computed decile expenditure share	implied daily calories from maize	quality scale	annual consumpt. corrected for quality	daily calorie adjusted for quality
1	2.82	34.77	0.74	-0.49	0.08	311.98	0.61	56.93	510.86
2	3.98	44.60	0.71	-0.48	0.07	400.22	0.73	61.29	549.99
3	5.11	53.11	0.69	-0.47	0.07	476.54	0.82	65.06	583.84
4	6.00	59.21	0.67	-0.46	0.06	531.28	0.87	67.77	608.12
5	7.00	65.58	0.65	-0.45	0.06	588.43	0.93	70.59	633.46
6	8.56	74.56	0.63	-0.44	0.06	668.97	1.00	74.57	669.18
7	9.55	79.78	0.61	-0.44	0.05	715.79	1.04	76.88	689.95
8	12.15	91.98	0.57	-0.42	0.05	825.31	1.12	82.30	738.52
9	15.22	104.04	0.52	-0.39	0.04	933.48	1.19	87.64	786.49
10	29.61	138.18	0.30	-0.29	0.03	1239.80	1.34	102.78	922.34

Table 3. Decomposition of projected demand

Decomposition of projected total demand in terms of growth of population, income per capita, world price, and real exchange rate between 2012 and 2023			
Variable	**2012-2023 projected rate of change**	**Approximated effect on demand in %**	**Explanation**
Population (1)	35.27%	35.27% (total demand)	population shift, holding per capita demand constant.
Real PPP income (2)	17.58%	9.26% (per capita demand)	income shift of per capita demand using arc elasticity of income, other things constant
Real world price (real US $) (3)	-48.73%	25.35% (per capita demand)	price response of per capita demand to world price change using approximate price elasticity and price transmission elasticity of 0.785
Real exchange rate (3) (the cost of a real $)	-22.39%	11.60% (per capita demand	price response of per capita demand to change in real exchange rate using approximate price elasticity and price transmission elasticity of 0.785
Projected per capita demand (5) as per calibration	48.11%	46.21% (per capita demand)	sum of income, world price, exchange rate effects on per capita demand. Linearized approximation
Projected total national demand (6) as per calibration and projection	100.35%	97.79%	combined estimated per capita and population effects (sum + product of relative changes). Note the approximation misses 2.56% of the projected change (100.35% versus 97.79%)