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John Beghin
North Carolina State University, beghin@unl.edu

Birgit Meade
USDA Economic Research Service, birgit.meade@usda.gov

Stacey Rosen
USDA Economic Research Service

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A food demand framework for International Food Security Assessment

John Beghin [a,*], Birgit Meade [b], Stacey Rosen [b]

[a] *Agricultural and Resource Economics, North Carolina State University, United States*
[b] *USDA ERS, United States*

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Abstract

We present a parsimonious demand modeling approach developed for the annual USDA-ERS *International Food Security Assessment*, a large-scale prospective assessment focusing on chronic food insecurity in 76 countries. 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 demand approach for four food categories. It relies on data on food availability, complemented by own-price and income elasticities and food price data. Beyond consistent aggregation, the framework exhibits desirable characteristics: food quality is increasing with income; price and income responses become less sensitive with income; and increasing income inequality decreases average per capita food consumption. The proposed approach is illustrated for Tanzania. We assess future food insecurity in Tanzania using the calibrated model and evaluate the impact of safety net policies and their budgetary costs. Food-insecure population is estimated as well as the implied food gap expressed in calorie per day per food-insecure person as well as in total annual food volume in grain equivalent. The food gap measure gauges the depth of the chronic food insecurity.

JEL classification: F17; Q17; D31

Keywords: International food security; PIGLOG demand; Income inequality; Food gap; Food policy

* Corresponding author.
E-mail address: jcbeghin@ncsu.edu (J. Beghin).

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1. Introduction

Food security assessments can be challenging because of data requirements and policy context (Barrett, 2002, chp 40; Kaicker & Gaiha, 2013; Makki, Tweeten, & Miranda, 2001; Ralston, 1997; Saleth & Dinar, 2009, among others). This is true for low-income countries trying to assess their own situation, but also for donor countries making aid and international assistance policy decisions to address food insecurity in poorer countries. This paper makes a methodology contribution to the literature on International Food Security Assessments (USDA-ERS, 2015; FAO-IFAD, 2014). These types of assessments are typically made with limited information because they cover a large number of countries, many of which have poor data collection systems. More specifically, the 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* (USDA-ERS, 2015). The *Assessment* projects food consumption per decile for 76 low- and middle-income countries for the forthcoming decade and estimates chronic food insecurity and food gaps. The approach could also be incorporated in partial equilibrium models such as IFPRI's Impact model, which typically estimates average food consumption in various countries using the same demand elasticity.

This paper presents a food demand system derivation for four categories of foods and by income decile. The approach relies on the PIGLOG[1] demand approach in a basic formulation. Decile food demands are consistently aggregated 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. Many demand systems do not allow for an explicit link between average demand per capita and a distribution of food across deciles. For each food category, the proposed approach explicitly incorporates a measure of the decile income distribution and provides an aggregation of decile demands into a market average demand for that category which is a function of average income corrected for income inequality across deciles, as explained below.

The approach accounts for two aspects of quality in food availability as it relates to income. First, as income rises, consumers demand more expensive calories by changing the composition of their food basket toward more expensive food groups. We account for that by having higher income elasticity values for non-staple food items than for grains and roots and tubers. Within staples, we have a higher income response for grains relative to roots and tubers. Similarly, price responses are stronger for more expensive food groups. Policies that affect prices of any of the four groups and/or consumer income will generate changes in the composition of the food basket and consequently changes in levels of calorie consumption since the four groups have different caloric density.

Second, the approach allows for variable quality of food items within food groups, with "quality" increasing with increasing income. "Quality" here refers to higher-value food products within a food group. We follow Deaton (1988) and express unit value (the price adjusted for quality) as having a multiplicative form of price multiplied or "scaled" by quality. We call this our quality scaling factor. Quality upgrade within any food group has been documented repeatedly (e.g., Deaton (1988); Deaton (1990); Grunert (2005); Reardon and Farina (2001); Van Rijswijk and Frewer

[1] PIGLOG stands for price independent generalized log-linearity. It is a class of demand systems that provide flexible structure with nonlinear income response and exact aggregation of individual demand into a representative consumer demand function of per capita income and, as shown later, the Theil entropy measure of income inequality.

(2008); Yu and Abler (2009), among others). The various qualities of a given food category are aggregated into an average-quality equivalent that leaves country-level data unchanged. Wealthier consumers purchase higher value/quality goods at higher prices relative to poorer consumers. Lower income deciles consume lower valued and lower priced calories, and these lower prices allow an increase in quantity, other things being equal. Within each good category, consumption of heterogeneous qualities can be aggregated over deciles in "average-quality" equivalent units. Our characterization of the quality spectrum across deciles uses information from FAO-IFAD's *State of Food Insecurity* (*SoFI*) (see FAO-IFAD, 2014) to estimate the calorie availability of the poorest decile. The integration of these two flagship estimates of food security (USDA's *Assessment* and FAO-IFAD's *SoFI*) combines the predictive power of the food demand framework and *SoFI*'s rich information of the current distribution of food availability.

Domestic and world markets are connected in the proposed approach, but with significant transaction costs and trade impediments. Domestic and world prices are linked through synthetic transmission equations including tariffs, real exchange rates, transportation, and other trade costs.

Cross-price effects are ignored because of the scarcity of cross-price estimates. Tanzania and the country's staple grain, corn, were chosen to illustrate the approach. The country is part of the U.S. Government's Feed the Future program (a development assistance program), and recent household surveys provide reliable consumption data. Detailed Excel files are available from the contact author.

Policy analysis to assess various food security policies can be undertaken within the framework as shown below, with small model modification to account for price policies and direct transfers affecting poor deciles but not others (see Karami, Esmaeili, and Najafi (2012), Jha, Gaiha, Pandey, and Kaicker (2013), and Ravallion and Van de Walle (1991) for food-security policy analysis).

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, that allows for nonlinear income response. It allows for an explicit aggregation of demand over 10 deciles for each good category to an aggregate market demand function of average per capita income corrected for income inequality, which is expressed using the Theil's entropy measure of income inequality (Theil, 1967) summarizing the income distribution over deciles (Muellbauer, 1975). Finally, with proper calibration, the PIGLOG specification easily exhibits shares of food expenditure that are decreasing with real income, a stylized fact of food consumption patterns. The expenditure shares per good category can be summed-up, and demands per category can be aggregated into calories or grain equivalent. In a first step, for presentation purposes, we assume quality as constant. Later, variable quality and prices are introduced using a scaling approach.

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

$$w_{\mathrm{i}} = A_{\mathrm{i}}(p_i/P) + B_i(p_i/P)\ln(x/P), \tag{1}$$

with variable x being the nominal income of the consumer, and with nominal price p_{i} and price index P for all other goods, which can be approximated by a CPI. 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 $w_i = A_{\mathrm{i}}(p_i) + B_i(p_i)\ln(x)$, with price and income variables being in real terms from now on.

Marshallian demand q_i is

$$q_i = (x/p_i)\,(A_i(p_i) + B_i(p_i)\ln(x))\,. \tag{2}$$

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

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

which is decreasing in income if B_i is negative. Eq. (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

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

Eq. (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.

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

The PIGLOG formulation allows for aggregation of decile-level demands for any good into the total market demand which can be expressed as an average per capita market demand which is a function of average income corrected by Theil's entropy measure of income inequality among income classes (Muellbauer, 1975) and which uses the same preference parameters as the demand of any individual decile.

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

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

Eq. (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 and Theil's entropy measure of income inequality z measured on the decile income distribution:

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

with

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

Entropy measure z reaches its maximum at 10 when all deciles have equal income. In this case $\ln(10/z)$ equals zero. Any income inequality leads to $(10/z) > 1$ and $\ln(10/z) >$ zero. Given some inequality and a negative value for $B_i(p_i)$, income inequality decreases the level of average consumption per capita for the corresponding good category. As shown in Eq. (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

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

We also define average expenditure share for good category i as

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

The elasticity of average demand for good i with respect to average income (or total expenditure) is

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

The own-price elasticity of the average demand is

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

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 according to their respective incomes.

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 (2015), which relies substantially on FAO data for food availability. From the decile income distribution data, one can compute the Theil inequality measure (Eq. (7)). Using Eqs. (9) through (11) for the average expenditure share and the two elasticities of average demand for good i, demand can be calibrated on the four parameters a_i and b_i. Elasticity estimates crome from Muhammad et al. (2011). Then, individual decile demands can be calibrated using the four 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.

The free parameter (chosen to be b_{io}) is used to ensure 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 parameter satisfies these stylized facts in the calibrated demand system. In point 1 below, we explain how we pin down b_o to a specific value. The calibration is recursive. Four steps are involved:

1 We pin down b_o such that the ratio of calibrated price elasticities for the bottom and top deciles are equal to the ratio of the natural logarithm of their national income shares in the base year. This ratio is 2.932 for Tanzania.

2 Parameter b_{i1} is recovered from the income elasticity estimate $\hat{\varepsilon}_{\bar{q}_i\bar{x}}$ and the given value of $\hat{b}_{io}$:

$$\hat{\varepsilon}_{\bar{q}_i\bar{x}} = 1 + (B_i(p_i)/\bar{w}_i) = 1 + [(\hat{b}_{io} + b_{i1}p_i)/\bar{w}_i], \quad \text{leading to} \quad \tilde{b}_{i1} = [\bar{w}_i(\hat{\varepsilon}_{\bar{q}_i\bar{x}} - 1) - \hat{b}_{io}]/p_i \ .$$

Tildes denote calibrated values.

3 The calibrated value of the a_{i1} parameter is recovered, given $\tilde{b}_{i1}$, an estimate of the own-price elasticity of the aggregate average demand for good i $\hat{\varepsilon}_{q_i p_i}$, and the observed average income and Theil index z. It is $\tilde{a}_{i1} = w_i/p_i(\hat{\varepsilon}_{\bar{q}_i p_i} + 1) - \tilde{b}_{i1}(\ln(\bar{x}) + \ln(10/z))$.
4 The calibrated value of parameter a_{io} is recovered from the average share of expenditure Eq. (9), $\tilde{a}_{io} = \bar{w}_i - \left(\tilde{a}_{i1} p_i + (\hat{b}_{io} + \tilde{b}_{i1} p_i)(\ln(\bar{x}) + \ln(10/z))\right)$. The calibration results are shown in Table 1.

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 Eqs. (2)–(4). Again, in this initial calibration, the quality of any good i is assumed constant across 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 aggregation over individual decile demands. 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 the Appendix Excel files for the base year of 2012.

4.1. 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. The price of vegetable oil is used as a representative price for “all other food.” Vegetable oil tends to be an important component of other foods in most countries, it represents a higher value food item typical for this group, and its international price is readily available. All prices are in grain equivalent.[2]

Synthetic price transmission equations are used to link the world and domestic prices. These are explained in detail in the next section. The transmission equation includes tariffs, other policies if available such as food subsidies and transportation costs from world markets to the domestic market, as well as the effect of the real exchange rate. They also assume a less than perfect transmission between world and domestic prices.

[2] To convert any food group quantity into grain equivalent we first express it in calories based on information obtained from the FAOSTAT food supply database and then divide by the country’s calorie content of grain, typically around 3.2 calories per gram of grain.

Table 1
Demand calibration and quality adjustment per income decile for 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
Theil index (ln(10/z)) computed from decile data	0.229018	Unitless
Average expenditure share (data)	0.04809	Unitless
Corn demand calibration		
b_o free parameter calibrated to constrain decile elasticity ratio to 2.932 (see page 7)	−0.01648207	
b_1 (computed)	−0.00001583	
a_1 (computed)	0.00030801	
a_o (computed)	0.23796806	

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 consumption corrected for quality	Daily calorie adjusted for quality
1	2.82	34.77	0.74	−0.56	0.080	311.98	0.85	40.76	365.77
2	3.98	44.60	0.71	−0.54	0.072	400.22	0.91	49.11	440.74
3	5.11	53.11	0.69	−0.52	0.067	476.54	0.94	56.34	505.59
4	6.00	59.21	0.67	−0.50	0.064	531.28	0.96	61.52	552.10
5	7.00	65.58	0.65	−0.49	0.060	588.43	0.98	66.93	600.66
6	8.56	74.56	0.63	−0.47	0.056	668.97	1.00	74.56	669.10
7	9.55	79.78	0.61	−0.45	0.054	715.79	1.01	78.99	708.88
8	12.15	91.98	0.57	−0.42	0.049	825.31	1.03	89.36	801.94
9	15.22	104.04	0.52	−0.38	0.044	933.48	1.04	99.61	893.85
10	29.61	138.18	0.30	−0.19	0.030	1239.80	1.07	128.61	1154.13

Table 2
Projected food insecure population in Tanzania (estimated with 2 food security targets and 2 methods).

Year	1800 calorie target				2100 calorie target			
	Food insecure population lognormal approach	Share of population lognormal approach	Food insecure population USDA decile approach	Share of population USDA decile approach	Food insecure population lognormal approach	Share of population lognormal approach	Food insecure population USDA decile approach	Share of population USDA decile approach
2012	11,571,381	24.67%	14,073,830	30%	18,944,397	40.38%	18,765,107	40%
2013	10,088,020	20.90%	9,652,388	20%	17,198,274	35.64%	19,304,777	40%
2018	4,581,702	8.26%	5,545,134	10%	9,541,100	17.21%	11,090,269	20%
2023	3,718,825	5.86%	6,346,112	10%	8,267,888	13.03%	12,692,225	20%

4.2. Aggregation over the four types of goods

Next, we aggregate the four food groups (major grain, other grains, R&T, and all other foods) to derive the total food demand. 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 converted into grain-equivalent (or any food item equivalence). The total demand responds to price and income via the economics underlying each of the four food demand components. Table 2 shows the calibration for corn per decile for Tanzania.

5. Price transmission

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 and food policy, and other transaction costs arising from bringing commodities to local markets. Each real consumer price for any tradable commodity i is linked to the corresponding world market price as follows:

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

where θ is the slope indicating the strength of transmission between the world price and the domestic price, ER is the nominal exchange rate in local currency units (LCU) 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. Full transmission implies θ is equal to 1.

The additive form of Eq. (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 and can be further lowered by setting the slope parameter θ to a value smaller than 1. In the Tanzania illustration we assume a slope θ of 0.73.[3]

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 Eq. (12). To compute Eq. (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, 2015 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 goods. 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 (in 2005 real prices), consistent with the range of domestic transportation costs in Africa as reported in Badiane, Makombe, and Bahiigwa (2014). World price data are obtained from USDA's Agricultural Projections. These transmission equations are reported in Table 1 of Beghin, Meade, and Rosen with the implied intercept between world and domestic price expressed in real LCUs.

6. Quality scaling

Consistent with real-world observation, it is assumed that the quality of good *i* increases with higher incomes and that its price is also increasing with quality. Therefore, low-income consumers consume cheaper quality foods 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 such that the product of quality-adjusted quantity consumed and prices (or the expenditure share) remains constant. The quality-scaling approach can be rationalized using the framework of Cox and Wohlgenant (1986) of hedonic prices in which households in different income deciles chose quality as part of their utility maximization problem. We do not attempt to model this hedonic choice explicitly here, however.

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

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

with

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

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 higher-income consumers do the opposite by consuming higher quality goods in smaller amounts once expressed in quality-adjusted units ($q^h_{iadj} \leq q^h_i$ with μ^h larger than unity).

[3] The magnitude of transmission coefficients is uncertain within a large range (0.002–0.99). See Amikuzuno and Ogundari (2013), and Minot (2011). Minot (2011) finds that staple food prices in Sub-Saharan Africa rose by about three quarters of the proportional increase in world prices in 2007–2008. Our 0.73 value is broadly consistent with Minot (2011).

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 Eq. (2) or in variable-quality units in Eq. (13)). To compute calorie availability, Eq. (13) is used. To calibrate the demand system, Eq. (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 Eq. (15) below.

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

$$q^h_{iadj} = (\alpha + \beta q^h_i), \quad \text{and} \quad \mu^h_i = q^h_i / (\alpha + \beta q^h_i)\ , \tag{15}$$

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

For the Tanzanian model illustration we use the 1st decile per capita food availability implied by FAO-IFAD's *State of Food Insecurity* (*SoFI*) in 2014 and updated data on food availability.[4] This availability for the 1st decile is 138.1 kg of grain equivalent (rounded) per year in Tanzania, or equivalently 1239 calories per day. Over time, this minimum consumption is allowed to grow slowly following the projected distribution of food availability in the country as explained in Beghin et al. (2014). Using Tanzania as an example, quality increases are incorporated by first scaling up each consumption for the four categories to achieve a minimum aggregate calorie intake of 1239 calories per day (or 138.1 kg/year) for the lowest decile in the base year. The quality scaling for corn is shown per decile in Table 1 (see column labeled "quality scale") for the base year. The range of quality differences across deciles shrinks over time if average real income and food consumption increase. 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 real income rises.

7. Decomposition of projected demand by its determinants[5]

Based on the calibrated demands over the period 2012–2023, total food demand for corn in Tanzania is predicted to increase by nearly 76% over the 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 30%. The interaction of population growth and that of per capita demand growth is responsible for 11% growth of total demand (76% = 35% + 30% + 11%). The latter figures are obtained using the calibrated demand (Eq. (8)).

The decomposition of the demand growth per capita indicates 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 (14%). The projected real appreciation of the Tanzanian currency, after proper scaling by elasticities, leads to 6% of per capita demand growth. The total price effect is roughly 20%, underscoring the importance of price policy. Finally, income growth contributes 9% of per capita demand growth. The approximation of per capita demand growth is not perfect, of course, and misses slightly less than 1%. The unaccounted for change

[4] See Beghin et al. (2014), Appendix, for a detailed explanation of how the average caloric intake for the first decile is estimated using *SoFI*.

[5] Beghin et al. (2014) describe the derivation of the decomposition (pp.18–19) which follows Heien and Wessells (1988), and Dong (2006).

comes from the interaction between price and income changes and from the linear approximation used to calculate the contribution of each factor.

8. Food security indicators

Two food insecurity indicators are estimated for the current year as well as ten years out: the number of food-insecure people and the food gap, explained below. The main focus and contribution of the *Assessment* model 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 estimate food demand, subject to income constraints and responding to price signals for the 10 income groups or deciles. This decile food demand is then compared with a nutritional target to determine whether a given income group is considered food secure.

We use two nutritional targets, based on a daily caloric intake standard of 1800 and 2100 calories per capita per day. The caloric target is converted into grain equivalent quantities. USDA has used the 2100-daily calorie target (234 kg of grain equivalent per year for Tanzania). The 1800-calorie target (201 kg of grain equivalent per year for Tanzania) represents an alternative for sedentary people. There is no universal standard for food security, but these two targets are plausible and provide a range. In the policy application we use the 1800-calorie threshold to look at the impact of food security policies.

We also use two distribution-of-income approaches, one based on the decile distribution of income following USDA's *Assessment*, the other based on a recovered lognormal distribution of food intake from *SoFI*. Using the decile approach, if the estimated average food demand in a decile falls below the target level, the entire income group (decile) is counted as food insecure. Aggregating the people in all food-deficit income groups provides one of our food insecurity indicators—the number of chronically food-insecure people. To gain understanding of the depth of food insecurity, we look at the food gaps between the estimated consumption level of food-insecure groups and the target level. The gaps for all food-deficit deciles are added up to determine the total amount of food required to allow each income decile to reach the nutritional target for a given year.

For the second distribution of income approach we rely on *SoFI* data to estimate the distribution of calorie availability, which is a monotonic transformation of the income distribution.[6] It indicates the shape of the distribution (lognormal, normal) and provides the mean caloric intake and the coefficient of variation of calorie availability based on income variation estimated from surveys. We use this information to characterize consumption as distributed with a mean m and variance v, explained in more detail in the Appendix of Beghin et al., 2014. The coefficient of variation (CV) of food availability for each country is $CV=\left(\frac{\sqrt{v}}{m}\right)$, where v is the variance of the empirical distribution which can be recovered given the mean and the CV as indicated in the Appendix for the base year. Assuming food availability q_{cal} is distributed lognormal, then $\ln(q_{cal})$ is distributed $N(\mu,\sigma^2)$ with $=\mu = \ln\left(m^2/\sqrt{v+m^2}\right)$ and $\sigma^2 = \ln\left(1+v/m^2\right)$. Once μ, and σ^2 are computed,

[6] *SoFI* provides information on the distribution of food intake for 170 countries.

we recover the proportion of the population that falls below the calorie target (1800 calories in the next equation) using the equation

$$\Phi^{in\sec ure} = \Phi((\ln(1800 - \mu)/\sigma) = \int_{-\infty}^{(\ln(1800)-\mu)/\sigma} 1/\sqrt{2\pi} e^{(\ln(1800)-\mu)^2/2\sigma^2)} dq_{cal}. \quad (16)$$

A similar equation holds for 2100 calories. Function Φ indicates the CDF of the standard normal distribution, and $\Phi^{insecure}$ indicates the proportion of the population that is food insecure.

Next, the average food intake of food insecure people, $q_{cal\,average}^{food\,insecure}$, can be recovered using the partial mean of the calorie availability below the target (1800 here in the equation), which is obtained using

$$E\left(ln(q_{cal}^{food\,in\sec ure})|ln(q_{cal}) < \ln(1800)\right)$$
$$= \mu - \sigma[\phi((ln(1800) - \mu)/\sigma)/\Phi((ln(1800) - \mu)/\sigma)], \quad (17)$$

and leading to,

$$q_{cal\,average}^{food\,in\sec ure} = e^{\mu - \sigma/\Phi^{1800}[\phi((ln(1800)-\mu)/\sigma)]}, \quad (18)$$

where ϕ is the standard normal density function. The food gap can be computed by looking at the difference between the target and the average calorie availability for food insecure consumers. This provides a gap in calories per day per food-insecure person. The latter can be multiplied by the population at risk and converted into volume of grain equivalent per year to yield a gap indicator based on annual grain volume as was done under the decile-approach.

Note that with this second approach the mean caloric availability for the country increases over time. If the *CV* is maintained constant, then the Theil entropy measure for that distribution is assumed constant as in the *Assessment*. Both mean and standard deviation are growing at the same rate to keep the income ratios (decile income/average income) constant in the Theil entropy measure. However, here we are dealing with the Theil entropy measure of calorie availability, which is slightly different than the Theil entropy measure of income, given that income elasticities decrease as income increases across deciles. We abstract from this possibility here.

8.1. Food security assessment

The assessment of food security is shown in Tables 2 and 3. Table 2 presents the projected population at risk for the two targets (1,000 and 2,100 calories/day) and the two approaches to income distribution and for projections over the decade (2012, 2013, 2018, and 2023). Table 3 shows the implied projected food gaps.

Recall that in the decile method, if the estimated food availability for any decile falls below the food security target (e.g., 234 kg or 2100 calories/day), the entire income decile is considered food insecure. Aggregating the people in these food-deficit income deciles provides the food-insecure population. The food-insecure population varies by discrete 10%-changes when population deciles come in or out of food insecurity.

Both approaches concur that population in the first decile will remain food insecure throughout the projection period even with the low target of 1800 calories. Using the more stringent threshold of 2100 calories, people in the two bottom deciles will remain food insecure in 2023. In those later years, the decile approach overstates the share of population (20%) that is food insecure compared to the distribution-based estimate of 13%.

Table 3
Food gap in calorie/day per food-insecure person and total annual food gap in grain equivalent (1000 mt).

Year	Average per capita daily calorie intake (projected for the whole population)	Food gap in calorie/day per insecure person lognormal approach	Total annual food gap in 1000 mt of grain equivalent lognormal approach	Food gap in calorie/day per insecure person decile approach	Total annual food gap in 1000 mt of grain equivalent decile approach
	1800-calorie target (201 kg/year of grain equivalent)				
2012	2430	337.1	435	300.6	471.4
2013	2538	322.3	362	362.9	390.4
2018	3105	264.9	135	216.8	133.9
2023	3306	250.3	104	114.7	81.1
	2100-calorie target (234 kg/year of grain equivalent)				
Year	Average per capita daily calorie intake (projected for the whole population)	Food gap in calorie/day per insecure person lognormal approach	Total annual food gap in 1000 mt of grain equivalent lognormal approach	Food gap in calorie/day per insecure person decile approach	Total annual food gap in 1000 mt of grain equivalent decile approach
2012	2430	464.2	980.0	494.5	1034.0
2013	2538	442.5	848.1	419.8	903.1
2018	3105	358.4	381.2	327.1	404.2
2023	3306	337.1	310.7	208.0	294.2

9. Policy analysis

Tanzania has a multi-pronged food security program (Baregu, Festo, Mwaijande, & Lein, 2015; Christensen & Cochrane, 2012; Haug & Hella, 2013) For the purpose of our illustration, we focus on policies that target food consumption and provide a safety net. First, the Tanzanian National Food Reserve Agency provides corn price subsidies to vulnerable and food-insecure households. In addition, cash-based programs have been used in recent years. For example, there has been a $220 million Productive Social Safety Net program using both conditional cash transfers and labor-intensive employment to augment incomes of poor households (Christensen & Cochrane, 2012). We compare these two policies by providing simulations of corn price subsidies and income transfers to vulnerable populations while ensuring equivalence in calorie intake. We then look at the consumption, food security, and fiscal consequences of these policies for the two deciles estimated to be food insecure. Results are shown in Table 4.

A first scenario examines the impact of $100 million, at 2005 prices, of direct transfers going to consumers in each of the two lowest income deciles ($200 million total which is close to the $220 million figure cited in Christensen and Cochrane (2012)). A second scenario considers a corn consumer price subsidy yielding an equal increase in food consumption. This equivalence in the increase in food intake allows for comparison of the two policies, which are then assessed based on their respective budgetary cost. The policies increase the calorie intake of the average consumer in deciles 1 and 2 by 31% and 19%. Corn subsidies cost $34.4 million for decile 1 and $31.3 million for decile 2. Hence, these corn subsidies to deciles 1 and 2 are a much cheaper way to induce increases in calorie intake than income transfers are ($100 million for each decile). Income transfers have a larger positive welfare effect on consumers since these consumers would likely consume more of everything, not just corn, but this is achieved at a much higher fiscal cost. Optimum policies to achieve increased food consumption for some deciles would call for decile-

Table 4
Food security policy analysis application (2012 calibration year).

Scenarios	Prices (schillings per kg)		Food consumption (kg of grain equivalent per year)				Average food gap per capita in kg/year (1800 calorie/day threshold)		Policy cost per decile	
	Quality adjusted corn price decile 1	Quality adjusted corn price decile 2	Corn consumption decile 1	All food consumption decile 1	Corn consumption decile 2	All food consumption decile 2	Food gap decile 1	Food gap decile 2	Policy cost decile 1 ($ million	Policy cost decile 2 ($ million)
Baseline	244.3	260.1	40.8	138.1	49.1	168.3	62.5	32.3	0.0	0.0
Direct transfer	244.3	260.1	45.4	154.4	52.9	182.1	46.2	18.5	100.0	100.0
Corn price subsidy	124.9	161.6	57.1	154.4	62.9	182.1	46.2	18.5	34.4	31.3

specific food price subsidies (Vousden, 1990). Here, more specifically, we look at corn intake targets in the case of the second policy. The policy could be implemented by giving vouchers to low-income households or people identified as food insecure to reduce their price of corn.

10. Summary

This manuscript presented a parsimonious modeling approach that incorporates price and income effects, quality variation, and consistent aggregation over income classes in a food demand system. The approach can be used to assess food security when information is limited and to undertake food security policy analysis. The methodology was illustrated using data for Tanzania to derive estimates of food insecurity (food insecure population share and food gaps), and to investigate the impact of two food security policies. Corn consumer price subsidies and direct-income transfers targeted to two food-insecure deciles were compared with respect to their budgetary implications. The price subsidy policy was found to be more cost-effective. The presented modeling framework is easily scalable to a large set of countries provided data and elasticity estimates are available, and food security policy options can be examined.

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