Cost-Minimizing Food Budgets in Ghana

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Abstract

Attaining the daily required nutritional recommendations is a major challenge in Ghana where the average person earns about $1.89 per day. A linear programming diet model is used to determine the cheapest basket of food items that satisfy the recommended daily nutritional requirements of the average Ghanaian. Initial findings show that an average Ghanaian requires $0.36 per day to meet his required nutritional needs. This would be met with a food basket made up of sorghum, yam, cassava, coconut and milk. With this food basket and the estimated food expenditure, the average person in Ghana would save about 80% of his/her daily earnings. Sensitivity analyses are also performed to test the robustness of the findings. The paper further highlights some of the limitations of the methodology.

Key words: *Developing countries; nutrition; minimum costs; linear programming*

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Introduction

Good nutrition promotes growth and development in children and improves their academic performance. It also improves productivity in people of all ages and helps prevent and alleviate many health problems (Smith and Haddad, 2000). However many people fail to attain their nutritional requirements and consume beyond the recommended levels, both of which constitute malnutrition, a current major health threat in sub-Saharan Africa, South Asia and other developing countries. In 1995 about 167 million children below five years old (about one-third of the children population) were estimated to be undernourished in developing countries, with about 50% recorded in south Asia alone (Smith and Haddad, 2000). Smith and Haddad (2000) also report that about one-third of sub-Saharan African children are undernourished. Between the year 2000 and 2002, about 852 million people were undernourished in the world as a whole, with about 96% living in developing countries (Muller and Krawinkel, 2005). Smith and Haddad (2000) projected the level of malnutrition among children in developing countries and report that, ceteris paribus, malnutrition will decline to 37.4% and 28.8% of the population in South Asia and Sub-Saharan Africa respectively by 2020.

Like in other developing countries, malnutrition is very prevalent in Ghana. Anthropometric measures of nutritional status show a strong nutritional pattern, with malnutrition roughly increasing from the southern to the northern part of the country (Alderman 1990). Between the 1960s and 1980s, an average of about 30.6% of Ghanaian preschoolers (< 5 years old) was chronically malnourished and another 7.8% and quite significant fraction of the adult population was acutely malnourished (Alderman, 1990). By the late 1980s, according to Alderson (1990), child malnutrition in Ghana improved by about 58% because of massive education on the benefits of good nutrition. Currently, malnutrition is still declining in Ghana, but at slower rate. The components of food budget in Ghana differ from one ecological zone to another. Whilst roots, tubers and plantains dominate the budget in the forest and rural coastal zones, grains (millet, sorghum and maize) dominate the food budget of households living in the savannah zone. The difference in zonal food budget components follows a pattern – The average Ghanaian only spends on food items that are not produced in his/her zone of residence. For instance savanna zone dwellers produce mainly roots and tubers and virtually nothing of grains. Because they do not produce grains, grains sell at a relatively higher price in the savanna zone compared to the forest zone where they are largely produced.

Problem Statement

The average Ghanaian earns \$1.89 per day (World Bank, 2008), and depending on the area of residence, spends 61 – 76% of this income on food. In view of this, although the national food balance sheet indicates that sufficient food is available (FAOSTAT), many people resort to eating mainly what they produce, or at least what is produced in their ecological zone of residence, in order to curtail food expenditures. This behavior tends to affect the nutritional status of Ghanaians as the locally produced food items in a particular ecological zone do not frequently make nutritionally excellent diets. Against this background, this study seeks to identify a combination of food items that can be purchased at a minimum cost and, at the same time, meet the nutritional requirements of the average Ghanaian.

Literature Review

The question of obtaining the Recommended Dietary Allowance (RDAs) at the lowest possible cost has been a matter of concern for quite a long time now. Garille and Gass (2001) illustrate that economic literature credits Stigler's (1945) diet problem for its role in present linear programming applications. Stigler's interest was to find how much of his chosen 77 foods would be consumed by a man weighing 154 pounds so that his intake of nine nutrients would be at least equal to the recommended dietary intake (as suggested by the National Research Council) while maintaining minimum costs. Stigler's RDAs of interest were calories, protein, calcium, iron, vitamin A, niacin, riboflavin, thiamine and vitamin C.

Stigler (1945) argues that no one before his study had attempted to determine the minimum cost of obtaining the amount of calories, protein, minerals, and vitamins which other studies have accepted as adequate or optimum. He argues that a minimum cost of an adequate diet is governed by the nutritive values and the costs of food eligible for inclusion. He reasons that the other conventional diets cost so much because dieticians take account of the palatability of foods, variety of diet, prestige of various foods and other cultural aspects of consumption. Only natural foods were included in his diets since vitamin pills do not contain all the nutrients needed for a man's good health. In his solution, Stigler identified nine food items that minimized costs while providing the required nutrients. His diet consisted of varying amounts of wheat flour, cornmeal, evaporated milk, peanut butter, lard, beef liver, potatoes, spinach and dried navy beans. Garille and Gass (2001) point out the inadequacies of Stigler's minimal subsistence diet in terms of palatability, variety, and overall adequacy. In her article describing the evolution of the diet model into a more acceptable menu-planning approach, Lancaster (1992) observes that "the solution to the least cost diet is the equivalent of the human dog biscuit." The combination of food items may not be desirable for consumption but nutrition and costs are controlled.

Darmon et al. (2002) illustrate that Linear Programming is important as it can be utilized to help explain observational studies by modeling underlying structures of food choice, independent of social or cultural factors or the declaration bias inherent to dietary surveys.

Model formulation and description

We use a model designed to find the cheapest combination of food items that satisfies the most important daily nutritional requirements. The model attempts to minimize the cost of food for a 22 year old Ghanaian male. According to FAOSTAT the following food items are the most significant in the food balance sheet of Ghana: cassava, yams, plantains, maize, tomato, rice, oranges, sorghum, coconuts, milk, poultry, cattle meat, and pig meat.

The model is specified as follows:

$$\text{Min } z = \sum_j c_j x_j$$

Subject to:

$$b_i \leq \sum_j a_{ij} x_j \leq b_i \quad i$$

$$x_j \geq 0 \quad j$$

$$\sum x_j \leq 3\text{kg}$$

The objective of the model is to minimize food expenditure, Z (in US$). X_j is the quantity (in kg) of food item *j*; a_{ij} denotes the amount of nutrient *i*, in one kilogram of food item j; C_j is the cost of a kilogram of food item j; and b_i denotes largest or smallest acceptable quantity of nutrient *i*. Constraints in the model include the maximum amount of daily food consumption and the minimum and maximum nutritional requirements: energy, protein, carbohydrates, vitamin A, vitamin C, iron, and calcium. According to Anderson and Earle (1993), where only minimum requirements are set, there is a tendency for a linear programming application to have solutions showing a gross imbalance of some nutrients. The Food and Agriculture Organization and the World Health Organization have documented the harmful effects that may arise from excess consumption of some nutrients. Vitamin D and excess calcium are associated with kidney stone formation. High levels of vitamin A are associated with hair loss, bone pain and dry skin. Specifying upper as well as lower limits for each nutrient in our model ensured that we prevented the problem of nutritional imbalance that is common in linear programming.

Data

The significant food items in the food balance sheet of Ghana and their producer prices were obtained from FAOSTAT. The producer prices were converted into U.S. dollars from the Ghanaian currency (Cedis). The minimum energy requirement (2400 calories) was obtained from U.S. Department of Health and Human Services (HHS). The average age (22 years) was obtained from 2000 population census of Ghana (Ghana Districts, 2006) and the corresponding nutrition requirements from the US Department of Agriculture (USDA). Three (3) Kg was used as the maximum amount of food that an average Ghanaian can consume.

The daily minimum and maximum amounts of each required nutrient (see table 1) were obtained from HHS and the Dietary Reference Intake, DRI (2009) respectively. The nutritional value of each food item was obtained from the USDA nutrient data laboratory (USDA National Nutrient Database for Standard Reference)

Table 1: Nutritional Content of Food Items

Food item	Price/kg	Energy/ Kcal	Protein (g/Kg)	Carbs (g/Kg)	Vitamin A (mcg/kg)	Vitamin C (Mg/kg)	Iron (mg/Kg)	Calcium (Mg/kg)
Cassava	\$0.12	1600	13.6	380.6	10	206	2.7	160
Yams	\$0.35	900	20.1	207.1	9610	196	6.9	380
Plantains	\$0.46	1160	7.9	311.5	450	109	5.8	20
Maize	\$0.29	970	33.4	217.1	0	62	5.5	20
Tomato	\$0.72	180	8.8	39.2	420	127	2.7	100
Rice	\$0.62	1120	23.2	235.1	0	0	5.3	100
Oranges	\$0.24	470	9.4	117.5	110	532	1	400
Sorghum	\$0.35	3390	113	746.3	0	0	44	280
Coconuts	\$0.15	3540	33.3	152.3	0	33	24.3	140
Milk	\$0.28	610	31.5	48	460	0	0.3	1130
Poultry	\$2.84	2720	113.9	0	740	15	15.7	1380
Cattle meat	\$2.54	2540	171.7	0	0	0	19.4	180
Pig meat	\$2.56	1280	210.6	0	20	0	8.7	130
Constraints		≥2400	≥56	≥130	900≤X≤3000	90≤X≤2000	8≤X≤45	1000≤X≤2500

Results

According to the model, \$0.36 is the minimum per day amount that the average Ghanaian need to spend on food to meet the necessary nutritional requirements. In order to achieve this minimum food expenditure, Table 2 below (see the 'level' column) shows that, the food budget must consist of 0.348kg of cassava, 0.058kg of yams, 0.173kg of sorghum, 0.212kg of coconuts and 0.747kg of milk. Table 2 below (see the 'marginal' column) further shows that although other food items like plantains, maize, tomatoes, rice and oranges as well as some meat products (poultry, beef and pork) are widely produced and consumed in Ghana, their inclusion in the food basket will increase the minimum food expenditure. Whiles consumption of a kilogram of plantains will increase food expenditure by \$0.393, consumption of tomatoes will increase it by \$0.645 per kilogram of tomatoes. For maize and rice, a kilogram consumption of each will increase food expenditure by \$0.185 and \$0.541 respectively. Quite insignificant is the \$0.03 that a kilogram of orange consumption adds to food expenditures. A kilogram consumption of any meat product: beef, pork or poultry would increase food expenditure by at least $2. Needless to say, the consumption of any of the above food items will increase food expenditure because they are relatively more expensive than the components of the food budget suggested by the model.

Table 2: Optimal Values of Food Items

Food item	Lower	Level	Upper	Marginal
Cassava	.	0.348	+INF	.
Yams	.	0.058	+INF	.
Plantains	.	.	+INF	0.393
Maize	.	.	+INF	0.185
Totamato	.	.	+INF	0.645
Rice	.	.	+INF	0.541
Orange	.	.	+INF	0.03
Sorghum	.	0.173	+INF	.
Coconut	.	0.212	+INF	.
Milk	.	0.747	+INF	.
Poultry meat	.	.	+INF	2.296
Bovine meat	.	.	+INF	2.076
Porcine meat	.	.	+INF	2.029

Table 3: Optimal Values of Nutrient Requirement

Nutrient	Lower	Level	Upper	Marginal
Energy	2400	2400	+INF	1.08E-05
Protein	56	56	+INF	0.002
Carbohydrate	130	341.47	+INF	0
Vitamin A	900	900	+INF	1.98E-05
Vitamin C	90	90	+INF	2.12E-04
Iron	8	14.307	+INF	0
Calcium	1000	1000	+INF	1.65E-04

As shown in Table 3 above, all the maximum constraints and the carbohydrate and iron minimum constraints are not binding in the model. The binding constraints in the model are minimum energy, protein, vitamin A and C and calcium requirements. According to Table 3 above, although these constraints are binding, a unit increase in the right hand side of any of them will not increase food expenditure significantly. A unit increase in the minimum energy, protein and calcium constraints will increase food expenditure by only $0.000010750, $0.002 and $0.00016504 respectively. A unit increase in the right hand side of the minimum vitamin A and C, on the other hand, will increase the food expenditure by $0.000019765 and $0.0002121, respectively.

Tables 4 and 5 below present the results of the sensitivity analysis. In general there were small ranges for the optimal solution when considering the prices of the food items presented in

Table 1 above. It would take a minimal altering of the price of a food item to cause the composition of the optimal food basket to change. However for the nutrient requirements a broader range was observed.

Table 4 Nutrient Constraint Sensitivity

Equation Name	Lower	Current	Upper
minreq(Energy)	1900	2400	3935
minreq(Protein)	42.67	56	72.28
minreq(Carbohydrates)	-INF	130	341.5
minreq(VitaminA)	353.4	900	3000
minreq(VitaminC)	23.56	90	173.8
minreq(Iron)	-INF	8	14.31
minreq(Calcium)	217.9	1000	1583
maxreq(Energy)	2400	10000000	+INF
maxreq(Protein)	56	10000000	+INF
maxreq(Carbohydrates)	341.5	10000000	+INF
maxreq(VitaminA)	900	3000	+INF
maxreq(VitaminC)	90	2000	+INF
maxreq(Iron)	14.31	45	+INF
maxreq(Calcium)	1000	2500	+INF
maxconsumption	1.538	3	+INF

Table 5 Food Item Sensitivity Analysis

Food item (/kg)	Lower	Current	Upper
X1 (Cassava)	0.07924	0.1197	0.1306
X2 (Yam)	0.1637	0.3515	3.958
X3 (Plantain)	0.06649	0.4599	+INF
X4 (Maize)	0.106	0.2907	+INF
X5 (Tomato)	0.07451	0.72	+INF
X6 (Rice)	0.08348	0.6241	+INF
X7 (Orange)	0.2083	0.2386	+INF
X8 (Sorghum)	0.1675	0.3502	0.4458
X9 (Coconut)	0.1222	0.147	0.231
X10 (Milk)	0.104	0.2767	0.6115
X11 (Poultry meat)	0.5445	2.841	+INF
X12 (Bovine meat)	0.4636	2.539	+INF
X13 (Porcine meat)	0.5343	2.564	+INF

For all the binding constraints, assuming non-degeneracy, any change in their right hand side values (see ‘current’ column of Table 4), regardless of how small, will result in a change of the model’s solution. The components of the food budget, and the marginal values of the food items, will however not change within the lower and upper limits (see ‘lower’ and ‘upper’ columns of Table 4) of each of the binding constraints.

If the price of a component of the food budget increase (decreases) by a small amount, the components of the food budget and the solution will remain unchanged, while food expenditure will increase (decrease). If an increase in price is outside the lower and upper limits (see ‘lower’ and ‘upper’ columns of table 5), the amount of that food item in the food budget will increase. However if the decrease is outside the range, the value of the food item will decrease. If the decrease is large enough the value will become zero (the components of the food budget will change).

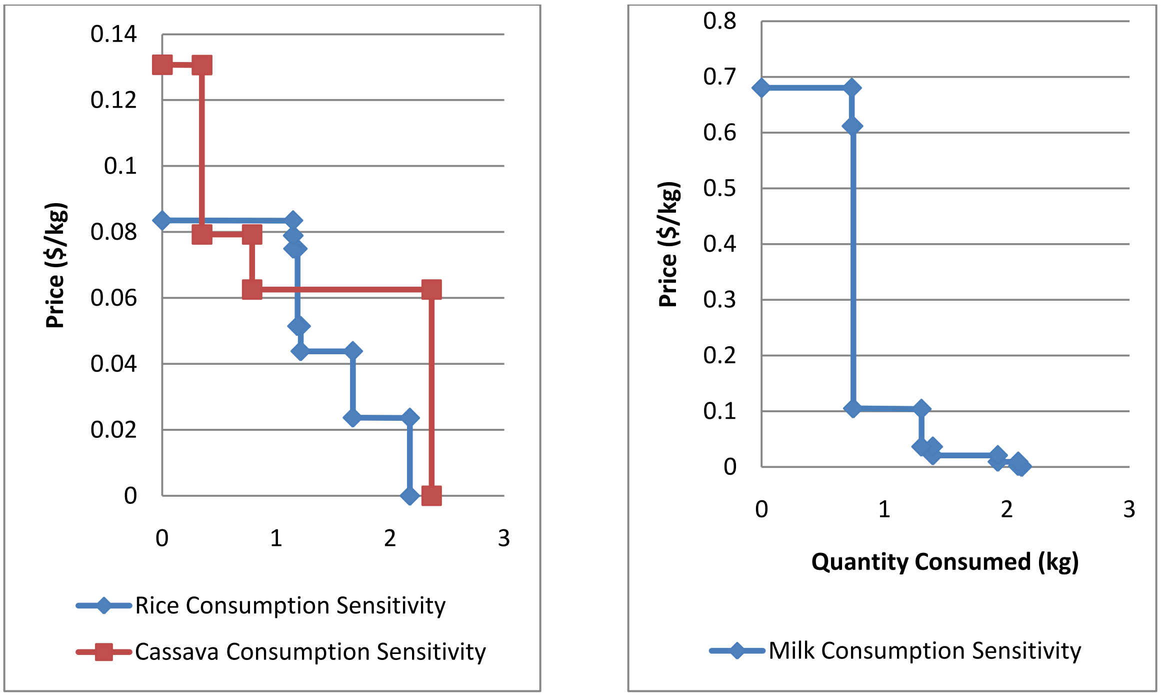

Figure 1 Sensitivity of Rice, Cassava, and Milk to Price Variation

Demand curves were developed for rice, cassava, and milk. As observed in Figure 1 above, these curves show the relative consumption of each food item that the model would advise given a change in price of the food item and keeping all other values constant. The graphs indicate that the quantity of milk suggested by the model is more sensitive to price changes than quantities of cassava and rice.

The model suggests a daily consumption of 0.747kg of milk. With reference to the Ghanaian setting however, this figure is too high to be acceptable. In view of this we constrained the maximum amount of milk that can be consumed to 0.5kg. This introduced oranges into, and cassava out, of the original food budget suggested by the model, and increased food expenditure by about 27.6%. It also increased the total per day amount of food consumption by about 19%; and increased the marginal values of the binding constraints and the food items that are not in the food budget. Further, the price of milk obtained from FAOSTAT seems quite low, so we increased it by 50% while maintaining the maximum milk consumption constraint. This affected the model in the same way as the maximum milk consumption alone did, except that the food expenditure increased by only 8.33% more than the original one suggested by the model. While maintaining the 50% increase in the price of milk, we decreased the maximum milk consumption constraint to 0.25kg. The effect of this on the model is similar to that of the 50% milk price increase plus the 0.5kg maximum milk consumption constraint, except that the original food expenditure increased by about 65% and the amount of each food item, particularly oranges, in the food budget increased significantly. When the price of milk was increased by 50% without the maximum milk consumption constraint, the components of the original food budget suggested by the model did not change, but the food expenditure decreased by about 29%; and the marginal values of the constraint and the food items that are not in the food budget changed. Next we decided to do away with milk in the model. When this was done, the original food expenditure increased by about 84% and orange was introduced into the original food budget. The daily consumption of oranges suggested by the model when milk was taken of the model is about 2.2kg, which is significantly higher than the other food items in the food budget. After this change any further manipulation of the model resulted in an unrealistic objective function value.

Discussion and Conclusion

The model simulation for the least cost diet determined that an average Ghanaian can spend \$0.36 per day on his nutritional requirements. The optimal solution is low because the average Ghanaian produces his own food and buys only the food items that he does not produce. The \$0.36 represents 19% of an average Ghanaian's daily income of \$1.89 (World Bank, 2008), and is significantly smaller than the 60-70% of daily income that is spent on food in developing countries. Therefore, if the findings of this model are adhered to, the average Ghanaian will be able to curtail food expenditure by about 40% and have enough of his income (about 80%) left for other financial obligations. Thus, all things being equal, human livelihood and poverty can be improved in Ghana if the results of this study are adhered to.

To satisfy his nutritional requirement while minimizing costs, an average Ghanaian should consume sorghum, yams, cassava, coconuts and milk. Cassava, yam, sorghum and coconuts are produced in many parts of Ghana, and thus readily available and frequently consumed by many people - both rich and poor. Unlike the other food items, milk is not readily available in some parts of the country because it is not widely produced. Thus, many people especially the rural dwellers hardly get access to milk. In view of this, all the food items recommended by the model, but milk, can be readily utilized by the average Ghanaian.

The minimum constraints on energy, protein, vitamin A, vitamin C and calcium are binding in the model. If the recommendations of this model are adhered to, the marginal values of the binding minimum constraints show that the nutrient intake of a Ghanaian can be increased without any significant effect on food expenditure. Assuming non degeneracy for all the binding constraints, any change in their right hand side values will result in a change of the model's solution. The components of the food budget will however not change within the lower and upper limits of each of the binding constraints. Note that the marginal values of the food items will also remain constant within the specified range. If the price of a component of the food budget increase (decreases) by a small amount, the components of the food budget and the solution will remain unchanged, while food expenditure will increase (decrease). If an increase in price is outside the lower and upper limits the amount of that food item in the food basket will change.

An important limitation of the study is our use of producer, instead of retail, prices of the food items, and the implications that this would have on the results. Food and Agriculture Organization (FAO) database had only producer prices. Meanwhile, producer prices do not necessarily present any problem where individuals consume their own produce as it would have cost them exactly the (producer) price to buy it. However problems come in when an individual has to buy a food item that is not widely grown in his region. If such a food item comes from a different region then it has to be purchased at the retail price. Taking this into consideration the food budget and the composition of our food basket would change.

Given the opportunity to rerun the model in the future, a better approach would be to use goal programming, a modification and extension of linear programming which provides a more systematic approach to the problem of balancing the supply of nutrients in a selection of food items (Anderson and Earle, 1983). Its application to the traditional food allows for the replacement of cost in the objective function by the total deviation of the nutrients from their requirements. This approach therefore ensures optimum nutritional balance within the existing framework of constraints established for the linear program.

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