Absolute Poverty: When Necessity Displaces Desire

by

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Abstract

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This paper proposes a new method for defining an international poverty line based on explicit budgeting. The novel feature is that linear programming is used to deduce the diet that minimizes cost and guarantees survival. Nonfood items are also explicitly budgeted and amount to about one quarter of the cost of subsistence. A series of least cost diets are calculated with increasingly demanding nutritional requirements for twenty countries using prices from ICP 2011. The aim is to see which requirements rationalize the spending pattern of the poor. The ‘reduced basic’ model does the job. When the cost of the nonfood items are added to the cost of the ‘reduced basic’ diet, the resulting Linear Programming Poverty Line (LPPL) averages $1.88 per day across the poor countries in the sample. The same model rationalizes both the spending pattern of the poor and the World Bank Poverty Line. The LPPL has the advantages that it is (1) clearly related to survival and well being, (2) comparable across time and space since the same nutritional requirements are used everywhere, (3) adjusts consumption patterns to local prices, (4) presents no index number problems since solutions are always in local prices, and (5) requires only readily available information, namely, the prices in ICP or equivalent.

JEL codes: I12, I32, O61, O63

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The World Bank recently announced that its famous international poverty line, originally set at $1 per day in 1985, had reached the value of $1.90 in 2011 prices. How do we interpret this? The line has always been controversial. Critiques span the gamut from the philosophical (Why not $.50 per day in 1985?) to the statistical (what index numbers should be used for comparisons between countries and for updates over time) to the existential (can you really live on $1.90 per day?).[1]

In this paper I propose a new method for defining the poverty line. This approach generates the current value of $1.90 per day, sidesteps the index number problems that bedevil its implementation, and provides a clear rationale for why $1.90 per day is a good standard. The present paper takes a 'basic needs' approach to defining the poverty line and uses linear programming to specify the nutritional component of the basic needs. Most non-food spending is explicitly budgeted. Since the diet amounts to about three quarters of total cost of subsistence[2], the poverty line is mainly the result of programming. This programming-based poverty line matches much of the consumption behaviour of poor people in different parts of the world, so the line can also be seen as an expression of their view as to what constitutes poverty.

The approach to poverty in this paper is an absolute one rather than a relative one. 'Absolute poverty' encompasses a potential ambiguity that must be clarified at the outset. Absolute zero on the temperature scale is the lowest possible temperature. By analogy, absolute poverty could be interpreted as the minimum standard that sustains life. No one could survive with a lower income, so no one could be living below the poverty line if bare survival were the standard. Instead, we mean a higher standard that signifies deprivation but which is never-the-less high enough, so that people could survive with less. The question is where that line should be drawn.

The first attempt to measure 'absolute poverty' in developing countries was that of Ahluwalia, Carter, and Chenery (1979), who chose a poverty line equal to the income of the forty-fifth percentile of the Indian population and used it to measure poverty around the world. This approach has been carried much further by the World Bank beginning with Ravallion, Datt, and van der Walle (1991).[3] They studied the relationship between national poverty lines and per capita income in thirty-three countries and showed that poverty lines increased with income. What was more surprising was that many poor countries had lines clustered around $1 per day in 1985, and that became the basis of the $1 per day.

Should we take this seriously? One justification for this measure of 'absolute poverty' is fundamentally subjective: the credibility of '$1 a day' rests on the presumption that it reflects what poor countries think poverty means. This argument is not convincing, however. The only poverty line that was the result of a local political process was India's, and the history of India's line suggests that political processes bring to the fore social conflict rather than broadly held views about the meaning of poverty. In fact, most of the poverty lines in low income countries were made up by social scientists, often westerners, many employed by the World Bank, for a variety of purposes. The subjective basis of the world

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[1]Recent contributions include Ferreira et al. (2015), Deaton (2010), Reddy and Pogge (2010), and Ravallion (2010).

[2]The average food share for the fourteen non-OECD/Eurostat countries using the reduced basic diet is 75%.

[3]Later contributions include Chen and Ravallion (2001, 2010), Ravallion and Chen (1997), Ravallion, Chen, and Sangraula (2009).

bank poverty line is, therefore, the view (or views) of social scientists about how much destitution constitutes ‘poverty.’ The clustering around $1 a day suggests that there is some consensus among them, but how much is uncertain. And the question recurs: Why at $1 a day?

The other basis for defining a poverty line would be an objective one in which a poverty line budget or some analogous construct is specified and applied across countries. I have tried to discover the poverty budgets corresponding to each data point in the Ravallion, Datt, and van der Walle sample in order to see if the poverty lines for the poor countries shared a common objective standard. It was not possible to find the budgets for all data points, but Table 1 shows the ‘food baskets’ defining the poverty lines for three of the countries–Egypt, Tanzania, and Kenya. The baskets specify the annual food consumption for one person as well as the fraction of total spending that food is supposed to have comprised. Non-food items are accounted for by dividing food spending by its share of the total. As a result, only food prices play a role in subsequent indexing. The Kenyan budget is the most austere in Table 1. It supplies only 1715 calories per day from two foods, and food accounts for three quarters of total spending. The Egyptian budget is more generous.

Table 2 shows three budgets for India. The Sukhatme (1961, 1965, pp. 120-1) budget was probably the basis for the first Indian poverty line of 20 rupees per month in 1962 (Rudra 2005, pp. 373-6) . The Dendakar-Rath (1971, p. 7) budget was less generous and was the Indian data point in Ravallion, Datt, and van der Walle. The Tendulkar (2009) budget was backed out of the Tendulkar Commission’s revision to the Indian poverty line (Allen 2013, pp. 8-9). The budgets vary considerably in their food shares (56% - 79%), in their calorie contents (1715 - 2311), and in the variety and character of the food.

The budgets look like they represent very different standards of living, and that impression is born out when they are costed. Figure 1 values the budgets in US retail prices, and Figure 2 values them in Indian rupees that are then converted to US dollars at the prevailing PPP exchange rate for personal consumption. The dispersion is large in both figures indicating the great differences in living standards among the various poverty lines. Pricing in rupees and converting to dollars yields a cost in dollars that is roughly half the cost of pricing in dollars, highlighting the difficulties in converting between currencies. Finally, the ranking of the budgets is different in dollars and rupees, illustrating the challenge that differences in relative prices pose for index numbers.

The international poverty live should avoid these problems. Ideally a line should (1) have a clear meaning related to survival, health, and well being, (2) represent a constant standard across time and space, (3) respond to local prices and any other pertinent local factors, (4) avoid intractable index number problems, and (5) require only readily available information.

In this paper I investigate the use of linear program for defining and measuring poverty. Linear programming is used to find the least cost diet meeting specified nutritional requirements. Non-food expenses are explicitly budgeted, as will be explained. They comprise about one quarter of expenditure, so the approach is primarily a programming one. This approach satisfies the requirements just listed and provides a systematic basis for the World Bank poverty line.

Specifying the poverty line diet with linear programming

The diet problem was the first linear programming problem ever formulated in a famous paper by Stigler (1945). The problem is to choose a diet from a list of foods that minimizes the cost of meeting a set of nutritional requirements. The objective function to be minimized is the cost of the diet:

$$\text{Cost} = \sum p_i F_i \tag{1}$$

where p_i is the price of a food and F_i is the quantity of the food consumed. The summation can extended over a list of t foods $F_1...F_t$, many of which will not selected in the solution.

The nutritional requirements are specified with a set of inequalities, each of which sets the requirement for one nutrient.

$$\sum n_{ji} F_i \geq R_j \tag{2}$$

Here the summation also runs over all of the foods indexed with i. R_j is the required amount of nutrient j–the minimum calorie requirement, for instance. n_{ji} is the quantity of nutrient j per unit of food F_i, for instance, n_{ji} might be the number of calories per kilogram of wheat flour and F_i, the kilograms of wheat flour in the diet. Each nutrient required in the diet has an inequality describing that requirement.

Finally, the consumption of each food has to be at least zero:

$$F_i \geq 0 \quad \text{for all i} \tag{3}$$

The linear program model presents a neat contrast to the standard model of consumer choice in its dual form. In that form, consumer goods are chosen to minimize the cost of meeting a specified utility level U*. The difference with the linear programming model is that the inequalities (2) are replaced by the utility constraint, equation (4) :

$$U(F_1...F_t) \geq U^* \tag{4}$$

This is the formal sense in which necessity displaces desire in the definition of absolute poverty.

These days, linear programs can be easily solved with the simplex algorithm in Excel. The solutions have two properties that are important for defining the poverty line. First, increasing the number of requirements or increasing the magnitude of a requirement either leaves the cost of the diet unchanged or increases it. A more nutritious diet is never cheaper than a less nutritious diet and may well cost more. Second, the maximum number of foods that solves the problem is equal to or less than the number of requirements. The number of requirements, therefore, limits the variety of the diet.

In his original investigation of the diet problem, Stigler (1945) used US prices from 1939 and 1945 to compute the cost of the least cost diet meeting a set of requirements including calories, protein, iron, niacin, calcium, vitamin C, vitamin A, thiamine, and riboflavin with values appropriate to a 'moderately active' man weighing 154 lbs. Stigler did not have Excel at his command but nevertheless reasoned his way to almost the correct answer. The solution for 1939 was 168 kg of wheat flour, 129 kg of dried navy beans, 23 kg of evaporated milk, 50 kg of cabbage and 10 kg of spinach. The values warrant comparison with ones we compute for poor countries in 2011.

Stigler's reaction to the solution has also been important: he thought the diet was impractical. "No one recommends these diets for anyone, let alone everyone; it would be the height of absurdity to practice extreme economy at the dinner table in order to have an excess of housing or recreation or leisure." (Stigler 1945 , pp. 312-3) This theme has been taken up by subsequent economists, who have tried to incorporate ‘palatability’ into the program. Smith (1959, p. 272) remarked that Stigler’s diet was “a dramatic illustration of how little purely nutritional needs have to do with the level of actual food expenditures...If we want diets that someone might be willing to eat, we need models that take account of tastes and habits.” This is surely true of people in rich countries whose behaviour is determined by preferences, income, and prices. Linear programming is much more germane to poor people, however. For them, survival is the issue, and the needs for survival take precedence. Preferences and income give way to nutritional requirements in determining consumption with prices still playing a role. Indeed, from the linear programming perspective, what it means to be poor is that your life is governed by linear programming, rather than standard consumer theory.

‘Nutritional requirements’ has an aura of scientific objectivity, and Stigler (1945) and Smith (1959) adopted lists of requirements issued by nutritional boards without criticism or examination. Indeed, it was the desire for an objective standard for poverty that motivated the research described here. However, it is clear on examination that the nutritional requirements set by bodies like the World Health Organization are in important respects subjective.[4] First, precise values for some nutrients such as calories and protein can be specified with reasonable accuracy, but for others that is not possible. Niacin, for instance, is necessary to prevent pellagra, and field observations suggest widespread appearance of pellagra in populations where adult men receive less than 7 mg of niacin per day. However, the current WHO requirement for adult men is set at 21 mg on the grounds that the higher value contributes to better health. The poverty line distinguishes the ‘poor’ from the ‘non-poor’. Should the line be set at 7 mg or 21 mg or somewhere else? Second, for geographical reasons, some required nutrients are not available to most of the world’s population. Iodine, for instance, is naturally available only to people living near oyster beds. Unless iodized salt is available, most people in the world would be iodine deficient, so there is no point including it as a requirement in a programming model defining a poverty line. Third, most of the world’s population is deficient in some nutrients. Riboflavin is an example. 90% of the Indian population is anaemic by current standards, which means they are deficient in iron, thiamine, or folic acid. Evidently, many ‘non-poor’ are deficient in these regards, so that full adequacy with respect to iron does not distinguish the poor from the non-poor. Perhaps ‘moderate anaemia’ should be the dividing line with correspondingly reduced nutritional requirements. Fourth, none of these standards takes into account the seriousness of the impairment to life that results from the deficiency. It may be that most people are unconcerned about vitamin A deficiency because night blindness does not appear a costly disability–at least not sufficiently detrimental to require the expenditure necessary to eliminate it.

These uncertainties affect the linear programming approach to diet in two important ways. First, we omit from consideration nutrients whose availability are locationally specific. Iodine is an example, as is vitamin D. People are not vitamin D deficient in sunny climates, although they may be deficient in cloudy, wet places. The poverty line is meant to distinguish the poor from the better off, and the availability of iodine and vitamin D do not do that.

Second, with respect to other nutrients, the linear programming approach takes on the

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[4]For a list of relevant WHO publications, most available online, see http://www.who.int/nutrition/publications/nutrientrequirements/en/

character of an estimation exercise rather than a purely objective determination of the optimal diet. In this paper, we are concerned with two 'estimation' problems. The first is whether there is a set of nutritional standards that generates the World Bank's $1.90 poverty line. The second is whether there is a set of nutritional standards that is common across the world and that rationalizes the diets that poor people consume. We argue that the answer to both questions is (approximately) yes, and that the same standards operate in each case. That means that the World Bank Poverty line does indicate what the 'poor' consume. Conversely, the choices made by the poor imply the poverty line. The poor have a voice in defining poverty–even if they are not aware of it.

Data and empirical specification

To investigate the World Bank's poverty line of $1.90 per day in 2011, we need prices from 2011. The principal data source is the ICP2011 core spreadsheet.[5] This was supplemented with the additional prices on several regional spreadsheets of which the African was the most useful. We investigate the implications of these prices for 20 countries ranging from the poorest to the richest (Table 3 onward).

While the ICP is a tremendous achievement, it is not complete, so it was necessary to add missing variables derived from extraneous sources. Some important additions included:

- the price of wheat flour. Wheat flour is of great importance in poverty measurement, but it was curiously missing from the data for the United States. This was particularly important since conversion to US dollars is a key part of the World Bank's exercise. Why the price is missing is altogether puzzling since it is available on the US Bureau of Labor Statistics website.[6] That price was used in the calculations reported here. Wheat flour prices were also taken from the national online retail price databases for some other countries.
- the price of cabbage. This turns out to be important since it is the cheapest source of vitamin C in many places. It was also missing from the USA data in the ICP2011 and the price was taken from the BLS database. In the case of some countries like the UK, the price of cabbage in 2011, which was missing, was estimated from relative prices in 2015 taken from supermarket databases. The same relatives were assumed to obtain in 2011.
- some missing USA and UK prices (like toilette soap, maize flour, and oatmeal in the USA) were taken from data collected in 2011 from supermarket web sites for earlier investigations.
- the price of electricity. This was necessary for the non-food component of the problem. ICP2011 lacks electricity prices for many south and east Asian countries.

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[5]The core prices was taken from *ICP2011: Data for Researchers* and the African prices from *ICP2011_AFR_Regional2011*. I am grateful to Nada Hamadeh and the World Bank for making these data available to me.

[6]http://www.bls.gov/regions/mid-atlantic/data/AverageRetailFoodAndEnergyPrices_USandMidwest_Table.htm

These were taken from the online tariffs of their electricity suppliers[7]. Information for some countries in 2011 was provided by Mr. Beni Suryadi of the ASEAN Centre for Energy, and his help is grateful acknowledge.

- The price of kerosene was missing for many OECD countries. Prices of kerosene or 'light fuel oil for households' were taken from IEA (2012).

Non-food consumption

In many poverty investigations, non-food expenditure is treated simply as a percentage mark-up on the food budget. The consequence is that the prices of non-food items play no role in the poverty assessment. I have tried to broaden the price base by specifying a non-food basket inspired by the historical poverty lines discussed in Allen (2011, 2013). The non-food basket consists of 3 metres of cloth (cotton or synthetic, whichever was cheaper), 1.3 kg of soap, and enough energy to supply 1.6 million BTUs of fuel for cooking and .4 million BTUs for lighting.

The energy requirements are those specified as the 'energy poverty line' in the Millenium Development Goals.[8] In terms of ICP2011, it was assumed that fuel for cooking was either electricity, liquified gas (propane or propane/butane mixture), utility gas, or charcoal, while fuel for lighting was either electricity, vegetable oil, candles, or kerosene. In each case, the cheapest source per BTU was calculated for each country, and that least cost source was used in the calculations. Generally, the least cost result was the common choice. Thus, charcoal was the cheapest fuel for cooking in most of Africa and either kerosene or electricity for lighting. In the developed countries, electricity for lighting and utility gas for cooking were usually the cheapest.

The non-food requirements were set with the tropics in mind. These requirements would be inadequate in cold climates. However, today most poor people live in the tropics, so the analysis has been confined to those latitudes.

Thus, the cloth allowance, which is the totality of purchases relating to clothing, looks adequate for tropical areas but not for others. 3 metres of light cloth is enough for one dishdasha or abaya per year but would not be adequate clothing in northwestern Europe, let alone Russia or Canada. No footwear is included in the basket. Medieval Englishmen and lower class Scottish women in the eighteenth century frequently were shoeless even in winter–Adam Smith (2007, p. 676) observed that Highland women "may, without any discredit, walk about barefooted"–but Russians and Canadian Inuit always had something on their feet in the cold season. The belted plaid cloak worn by poor Highlanders in the eighteenth century was wool, not cotton.

Moreover, the fuel requirement is adequate for the tropics but not colder climates. Engineering studies indicate that the fuel requirement is a minimum for cooking, but there is nothing beyond that for heat. In cold climates, much more fuel was often consumed than

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[7]See appendix of online sources for websites consulted.

[8]Modi, McDade, Lallement, and Saghir (2006, p. 9). As it happens, these requirements are very close to the energy consumption levels in the subsistence baskets in Allen (2011, 2013). There is a large literature on energy poverty including Katsoulakos and Kaliampakos (2014), and Pokharel (2004). Barnes, Khandker, Samad (2011, p. 899) use a demand curve approach that implies in higher requirements–9.1 million BTUs per person.

indicated by the Millenium Development Goals. English agricultural labourers in the eighteenth century consumed more fuel–about 5 million BTUs per person, so they had heat beyond the needs of cooking. In the early nineteenth century people in southern Sweden consumed 12 million BTUs per year, while in northern Sweden the average was 28 million (Kander 2002, p.26, 31ftnt 37). Canadians are estimated to have been burning 100 million BTUs of wood per year at the same time (Unger and Thistle 2013, pp. 35-7) A counter note, however, is struck by Russia. Budgets of working class families in St Petersburg in 1907-8 indicate that the average fuel consumption was somewhat less than 2 million BTUs per person (Mironov 2010, p. 54). Either Russians were very cold or so many people were crowded in one room that the sum of their meagre fuel spendings was enough to keep everyone warm.

While most non-food expenditure has been explicitly budgeted, housing has not been. ICP2011 includes housing rental prices, but the data were not complete enough for this analysis. Instead, the cost of housing was estimated as 5% of the budgeted food and non-food spending.

least cost diets: 1700 calorie model

We begin by examining the diets implied by various nutritional requirements.[9] We consider them in an increasingly stringent progression. There are five models in the sequence. Each contains all of the nutrients of the previous step and increases the quantity of those nutrients or adds additional nutrients or both.[10] The models are:

- **1700 calorie** model. The only requirement is 1700 calories per day.
- **CPF** model. Three nutrients are required: 2100 Calories per day, 50 g. of Protein, and 55 g. of Fat
- **reduced basic** model. CPF requirements plus half of the Indian recommended daily allowances (RDA) of iron, folate, thiamine, niacin, and the RDA of vitamins C and B12.
- **basic** model. CPF requirements plus the Indian recommended daily allowances of iron, folate, thiamine, niacin, and vitamins C and B12.
- **full course** model. Basic model plus RDA of six more vitamins and minerals.

We begin with the most elementary requirement–calories. What is the minimum cost of a diet that supplies just enough calories for survival? By ‘survival’ we do not mean the minimum for a single adult to subsist from one day to the next but rather the minimum, on average, for the species to survive. Adults must have enough energy to work and children to

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[9]Each requirement is expressed as an inequality in the form of equation (2). The quantity of each nutrient per kilogram of food (n_{ji}) must be specified. Generally the values used were those shown on the US Department of Agriculture, *National Nutrition Database* website. Some values, however, were taken from the regional nutritional databases listed in the online references. These data bases often do not agree with each other, and it might be important to investigate these discrepancies, but that has not been done here.

[10]Details about the linear programs are found in the appendix ‘notes on the linear programming.’

grow.

The minimum society-wide average can be established in two ways. One is by calculation.[11] The distribution of the population by age and sex is determined, and the energy required for basal metabolism for each age-sex group is calculated with standard formulae. The results depend on the average height of each group and the Body Mass Index that each is expected to maintain. Additional allowances are also required for pregnant and lactating women. Basal metabolism of each group is then increased by its physical activity level (PAL). Determining the PAL requires constructing an activity schedule across the year, so that the appropriate mark-up can be applied to each hour (the physical activity ratio or PAR) depending on exertion. More strenuous activities get higher PAR's. The PAL can then be computed as the average of the PAR's over the year.

Calculations along these lines point to around 2000 calories per person per year as the average requirement. This provides enough for some people to work very hard and for children to have enough energy to grow. The requirement varies depending on the age distribution of the population: faster growing populations have more children and a lower average calorie requirement. Calculations by the Food and Agricultural Organization (2008, p. 8) indicate a requirement of 1600-2000 calories per person per day. The US Department of Agriculture (2010, p. 2) uses a standard of 2100 calorie per person per day (with an unspecified variation across regions) in assessing food security. I have computed the same figure for Britain in 1841 assuming that the average man was a carpenter and the average woman a domestic spinner (Allen 2013).

The second approach to determining calorie requirements is to look at what people actually consume. Survey data for India shows that the poorest decile of the population consumes about 1450 calories per person per year (Deaton and Drèze 2009, p. 47, Suryanarayana 2009, p. 35). This is below basal metabolism, so it is either an error, or it indicates an unusual demographic structure (which means it is not relevant for society as a whole), or the population is dying out (in which case the standard is too low).

The second decile from the bottom consumes on average 1700 calories per person per day (Suryanarayana 2009, p. 35). This is just above the lowest FAO value and about the bare minimum a group requires for survival.

In view of these considerations, linear programming diets were calculated with the only constraint being 1700 calories per person per day. The implied diets are in Table 3. With only one constraint, there can be only one food in the solution to the programming problem. For 12 countries that is a cereal or flour. For the other eight, it is vegetable oil. The appearance of oil is unexpected, and it is probably also a recent phenomenon in world history. It reflects the widespread cultivation of palm oil in south Asia, a development of the late nineteenth century. Before that, rice or some other grain was the cheapest source of calories around the Pacific Ocean.[12]

It is a tricky question whether man can live by maize alone, but surely he cannot live solely on vegetable oil. Aside from fat, it supplies no nutrients. A population could not

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[11]FAO (2001) explains the methodology.

[12]Linear programs like those reported in this paper have been run with price data collected by Lockyer (1711, pp. 148-151) in Canton in December, 1704. Rice rather than oil was the solution to the 1700 calorie model, indicating that oil was a more expensive source of calories than rice.

survive on the vegetable oil diet. Requiring only calories leads to death rather than survival.

Least cost diets: CPF model

More satisfactory diets are implied by imposing more requirements. The second class of requirements are the principal nutrients–calories, protein, and fat. In the calculations, we increase the calorie requirement to the USDA value of 2100 per day. This allows people a more ample supply of energy to do the work that sustains society as well as raising children. Protein is set at 50 grams per person per day. The ultimate basis of this value is experiments that measure the nitrogen intake required to match the body's excretion of nitrogen and thus to maintain the body's nitrogen stocks. Fat is set at 55 grams per person per day. These requirements depend on body mass, age, sex, pregnancy, lactation, and so forth. In these cases (as with all other nutrients to be considered), the value of the requirement used in the linear program is calculated from age and sex specific requirements as a society-wide weighted average using the age and sex distribution of the Indian population as weights.[13] Recommend values for India are used, as they are more likely to reflect conditions in poor countries today than global recommendations.[14]

Tables 4 and 5 summarize key features of the diets as functions of the nutrient requirements. Table 4 shows average annual food consumption in kilograms. With the 1700 calorie diet, the average was 132. This increased to 199 kilograms with the CPF diet. The number of foods in the diet also increased (Table 5). There was only one food chosen with the 1700 calorie diet. The linear programming solution allows up to three foods with the CPF diet. Three foods are chosen in eleven cases and two foods in nine for an average of 2.55 foods.

The diets that solve the linear program with the principal nutrients as constraints are shown in Table 6. Consumption of oil is cut dramatically to plausible levels. Wheat is the staple in wheat growing areas, as is rice in southeast Asia. Maize diets are common. Legumes are consumed in nine of the cases. It is significant that the diet is purely vegetarian and that no alcohol, sugar, or vegetables (other than the legumes) are consumed. There is no sugar, no alcohol, and virtually no meat in any of the diets implied by linear programming.

Least cost diets: reduced basic and basic models

While the CPF diets provide better nutrition than the 1700 calorie diet, they none-the-less suffer many deficiencies. We begin with those that could lead to four of the most common and serious deficiency diseases. Pellagra is due to insufficient niacin, beri-beri to a

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[13]The nutritional requirements are from Rao (2009) and the population structure from http://esa.un.org/unpd/wpp/Excel-Data/population.htm

[14]The RDAs include an allowance for losses during cooking. "Considering the cooking loss of 50%, the RDA of ascorbic acid has been set at 60 mg/day." (Rao 2009, p. 287). An advantage of using India RDAs is that the cooking losses are assessed in terms of Indian culinary practices, which are probably more representative of poor, tropical countries than the cooking practices in the West. See Rao (2009, pp. 14, 246, 248, 251, 257, 262, 272, 274, 275, 279, 286) for more examples.

lack of vitamin B1, scurvy to insufficient vitamin C, while anaemia can be due to inadequate levels of either iron, thiamine, or folate (folic acid). Table 7 reports nutritional consumption relative to recommended daily allowances for these nutrients in the CPF diet.

In most cases, the CPF least cost diets meet the requirements for calories, protein, and fat exactly. Only in the case of China is the calorie constraint significantly exceeded. So far as the minerals and vitamins are concerned, the diets supply no vitamin B12–this is found only in animal products–and none or only negligible quantities of vitamin C. The absence of vitamin B12 means that anaemia would be widespread unless consumption of B12 were inadvertent. In India, "since populations subsisting essentially on foods of vegetable origin do not show evidence of widespread vitamin B12 deficiency, it is speculated that polluted environment and unhygienic practices could be providing the necessary minimal vitamin B12." (Rao 2009, p. 278) The lack of vitamin C implies widespread scurvy.

There is a likelihood of other deficiency diseases as well. Two kinds of diets are particularly deficient. The first are the rice-based diets deduced for Vietnam and Myanmar. These diets have low enough niacin levels to suggest wide-spread pellagra and low B1 levels indicating a risk of beri-beri. It is significant that the short-grain, milled rice which they consume is particularly lacking in these nutrients. In contrast, the brown rice consumed in Sri Lanka supplies more niacin and thiamine, so the deficiency problems are not so severe.

The second kind of diet that indicates a likelihood of deficiency diseases is the wheat -based diet of France, Algeria, Lithuania, and Bangladesh. Refined wheat flour in these countries is not enriched, so it lacks niacin and thiamine. Otherwise similar diets in the USA, UK, Turkey, and Mexico do not lead to these inadequacies because the enrichment of wheat flour is mandatory. The comparison indicates the desirability of mandatory food fortification.

In terms of the linear programming, the deficiencies can be cured by imposing the requirements on the solution. As noted previously, we compute the requirements from the Indian recommended daily allowances by computing the weighted average of the RDAs for the various age and sex groups. These average RDAs have been imposed in two variants, however. One variant is to impose them without modification. This is the 'basic model.' The other is to reduce them. This is the 'reduced basic model.' The reason for reduction is that the Indian RDAs may be too stringent. The requirements for iron, B12, and folate are set at a level to prevent anaemia. However, most of the Indian population is anaemic: "Even higher income groups are victims of widespread anaemia." (Rao 2009, pp. 200-1) So the Indian RDA sets the standard too high to separate the rich from the poor. Likewise, the RDA for niacin is about three times the level observed in populations suffering from pellagra (Rao 2009, p. 258). To lower the bar, the reduced India RDAs for the minerals and vitamins are set at half of the value of the RDAs (with the exceptiona of vitanim B12 and vitamin C, which are left unchanged to keep animal protein and vegetable consumption at their already modest levels).

The introduction of either the reduced RDAs or the unmodified RDAs has important implications for the linear programming solutions. First, the number of foods in the solution increases from 2.55 on average in the CPF diet to 4.75 with the reduced basic model and 5.15 with the unmodified RDAs. The increase is due mainly to the addition of an animal product and a vegetable. Second, the volume of food consumed over the year also goes up from 199 kg with the CPF diet to 269 kg with the reduced basic model and 317 kg with the basic model.

Table 8 shows the diets implied by the reduced basic model and Table 9 shows the implications of the basic model. There are two immediate consequences of requiring these vitamins and minerals. The first is the appearance of animal protein as a consequence of requiring vitamin B12. The linear programming solution generally implies either the cheapest available fish–usually mackerel–in coastal districts or milk in inland regions. Meat in any form rarely appears in the solution to a linear program. The second is the appearance of vegetables–most commonly cabbage–or cassava. These are sources of vitamin C. The B12 and C requirements are independent of the others, so adding these requirements to the program has scant impact on the rest of the diet. Qualitatively, the pattern of food consumption is similar in the CPF and reduced basic model. The same grains are generally consumed in the same regions. Total food consumption rises because of the introduction of animal protein and vegetables.

The increase in total food consumption has another implication that becomes increasingly important, namely, the overshooting of requirements. In the CFP diet and the reduced basic diet, most solutions meet the calorie, protein, and fat constraints exactly. The average degree of overshooting is only a few percentage points and it is not markedly higher with the reduced basic diet than with the CPF diet. In contrast, there is considerably more overshooting with the unmodified Indian RDAs in the basic diet. One third of them overshoot calories, and the average excess is 11%. Virtually all of the diets overshoot protein, and the average excess is 25%.

full course model

The vitamins and minerals considered thus far are only a subset of all of the nutrients that might be considered. Recommended daily allowances have been set for many others. To explore the implications of some of these, requirements for vitamin A, B6, riboflavin, calcium, magnesium, and zinc have been added to the linear program.

The exercise has a surreal air because of difficulties in defining and assessing deficiencies. In the case of vitamin B6, for instance, it is difficult to measure the extent of deficiency in the population (Rao 2009, pp. 260-3). Setting RDAs is difficult in some cases (vitamin B6) and fraught with conflicting considerations in others. Calcium requirements depend on vitamin D and protein intake. Low protein consumption reduces calcium requirements meaning that standards set for rich people are too high for poor people, and by some measures most Indians look like they get enough calcium. On the other hand, femur fractures occur at younger ages amongst poor women in India suggesting there might be an issue about calcium adequacy after all. (Rao 2009, pp. 158-9) At what level should the calcium RDA be set? In other cases, it is not clear how serious the deficiencies might be. A lack of vitamin A leads to night blindness, but how costly is that? (Rao 2009, p. 296) In other cases, deficiencies are so common or so rare that the intake of the nutrient provides little information about poverty or wealth. Thus, “dietary deficiency of riboflavin is rampant in India...only about 13% households meet the dietary requirement.” (Rao 2009, p. 251) In contrast, “the available reports...in India...do not report any widespread zinc inadequacy.” (Rao 2009, p. 225). In neither case, does the RDA provide a boundary that distinguishes poor people from better off people.

Introducing these additional vitamin and mineral requirements has a big impact on the results. The number of foods in the diets rises from an average of 5.15 with the full Indian diet to 6.35. In addition, more nutrients are obtained by increasing the quantity of food consumed in a year from an average of 317 kg with the basic diet to 409–an increase of almost one third. The Chinese diet with these requirements weighs 799 kg. Increasing the volume of food to this extent leads to considerable overshooting of calorie requirements (by

12%) and especially protein requirements (by 34% on average).

Comparison of the details of the full course diet (Table 10) to the basic diet shows some unusual changes. There is an increase in maize consumption, for instance. The consumption of vegetables and potatoes reach extreme limits. These features raise questions about the empirical relevance of the diets.

The full course diets have affinities with Stigler's original linear programming diets. The same foods turn up, and the quantities are of similar sizes. The reason is that Stigler's nutritional requirements include calories and protein as well as most of the vitamins and minerals we are considering. Stigler's specification did not include a fat requirement, and its absence explains why there is no oil or butter in his solution.

Linear programming diets and the diets of the poor

Stigler warned us that linear programming diets provided no guidance for the behaviour of Americans, and indeed, the solutions he found do not described what Americans ate in the 1930s and 1940s. Does this judgement apply to people in 'absolute poverty' in poor countries today? With some qualification, the answer is no. Linear programming explains many features of their behaviour.

We have examined a range of five linear programming solutions reflecting different levels of required nutrition. Not all of these explain behaviour. For many countries, a pure vegetable oil diet was the solution in the 1700 calorie diet. That diet cannot sustain life and no one consumes it. What people do is rationalized by more nutritious requirements. Likewise, the full course diet does not explain the behaviour of the poor since it requires more food than they consume. Half a ton of food a year exceeds per capita consumption in much of the world in the 1960s and so does not describe what they poor were eating. We are left with the CPF, the reduced basic, and the basic model as candidates for describing behaviour.

None of these models explains everything. There is more variety in actual diets than in the solutions. Milk is often indicated by linear programming; in practice, milk could be converted domestically to yogurt, which is commonly observed. Typically a single vegetable appears in an linear programming solution. It is the cheapest source of vitamin C. In actuality, people consume more than one kind of vegetable over the course of the year–partly because of seasonal variations in prices that are now captured in ICP2011 and partly for variety. This can usually be achieved at little cost since vegetable prices and composition are similar. Linear programming is not good at modelling the variety of vegetables that people consume, although it gets the order of magnitude right for the total weight of the vegetables.

What linear programming can do is identify the main structural components of the diet and their magnitudes. Some foods are rarely, if ever, solutions to the linear programming diet problem–meat, alcohol, and sugar, for instance. In the life of the poor, these foods are usually consumed only under exceptional, festive circumstances. Linear programming does not explain festivals. Linear programming solutions, as we have seen, are vegetarian diets centred around a principal grain that supplies most calories with a small amount of fish or milk, a vegetable, some oil, and often a legume. These are the main foods of the poor both historically and today.

The diets in Tables 1 and 2 illustrate these points. Food consumption ranged from 199 kg per person per year in the Kenyan diet–this is the average value for the CPF diets–to 360 kg in Sukhatme's recommended Indian diet, which lies between the basic and full course diets (Table 4). Grain consumption ranged from 123 kg to 205 kg, the consumption of animal products was appropriately low in all the diets, and legume consumption was in accord with the linear programs. The main differences between these diets and the linear programming solutions are (1) the inclusion of sugar, which is never chosen by linear programs, (2) a frequent absence of vegetables, and (3) values of oil consumption that look low in comparison to the linear programming solutions.

The African price data are particularly rich since the African regional price data include prices for a variety of grains consumed on the continent. While the core price list contains white maize flour, the African list also includes white maize grains, yellow maize grains and flour, as well as millet grain and flour and red and white sorghum grains. This richness allows linear programming to choose amongst a wide range of grains, and it generally choses correctly (Figure 3). Thus, in Zimbabwe, the diet is centred on white maize grains, while in Niger millet (or sorghum when nutritional requirements are demanding) is the solution. In Gambia, it is maize and millet, and in Liberia rice, the traditional staple, is selected unless the nutritional requirements are demanding when wheat replaces rice. In Algeria, wheat flour and bread are the main staples, and in Egypt white maize grains are chosen unless nutritional requirements are high when wheat flour is added. In all of these cases, the linear programming solution is the staple of the poor.

Results for some parts of Asia are equally successful. In Turkey, the diets are based on wheat with maize also playing an important role. Milk, oil, and vegetables are also consumed, while legumes significantly are not part of the solution. This corresponds to the traditional diet of eastern Anatolia. Rogers (1871, p. 800) explained that among the peasants in Kurdistan the "diet is simple enough, consisting of 'boorghul' –bruised hulled wheat, made in the house, boiled into a pilaf with butter, milk, sour milk, yaoort–and bread. Meat they use sparingly and then only in the summer when it is cheap...They only eat twice a day; in the morning bread and yaoort, in the morning a boorghal pilaf and yaoort. Their principal consumption is bread." Palgrave (1871, p. 737), the British consul in Trebizon, reported that "The peasant's food is mostly vegetable...Maize bread in the littoral districts, and brown bread, in which rye and barley are largely mixed for the inland provinces, form nine tenths of a coarse but not unwholesome diet. This is varied occasionally with milk, curds, cheese, and eggs...Dried meat or fish are rare but highly esteemed luxuries." These diets sound like the results of the linear programs for Turkey. Unfortunately the importance of rye and barley cannot be explicitly assessed since their prices are not included in the ICP, although they were probably similar to maize prices.

Likewise, the linear programming solutions for south Asia are plausible depictions of reality. Rice is the main staple, legumes are important, as are vegetables, oil, and fish or eggs.

The linear programming solutions for India are puzzling, for they indicate that the least cost diet is based on maize flour. Maize, however, is not widely consumed, and, indeed, even the poorest eat considerable quantities of rice or wheat, which are more expensive than millet and sorghum, which are the widely available cheap grains. These issues cannot be fully explored with the ICP2011, for millet and sorghum are not included in the core price list. Moreover, there is considerable regional variation in food prices, which is not captured in the ICP, which only reports national values.[15]

An important reason, however, why the linear programming solution does not reflect

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[15]See the reports for each crop in the series 'Selected State/Centre-wise Monthly Retail Prices of xxx in India' where xxx is a food product in www.indiastat.com

the consumption of the Indian poor is because wheat flour looks overpriced in the ICP. The price of wheat flour in the ICP is 27.54 rupees/kg, while the price of maize flour is 17.57 rupees/kg. In the Indian publication, “Average rural retail price of selected commodities/services in India,” the price of wheat atta in 2011 was 18.86 rupees while maize atta was 18.17 rupees. These relative prices have prevailed for years. If the Indian rural prices are used in the linear program instead of the ICP prices, the least cost diet shifts towards more expensive grain and becomes 127 kg wheat flour, 48 kg maize flour, 70 kg milk, 13 kg oil, and 41 kg cabbage with the reduced basic model. This is along the lines of the food consumption pattern of the poor in wheat growing parts of India. Wheat completely replaces maize when the basic model is used and even when the requirements are simply CPF. The poor in India eat wheat rather than maize because wheat has more protein and more niacin than maize. Their diets are not driven solely by the cost of calories.

Indonesia, China, Thailand and Bangladesh are anomalous, and they present important issues of interpretation. Rice is the staple food in these countries, and yet the linear programming solutions indicate maize and wheat flour are the implied carbohydrates. In the case of Indonesia, maize amounts to one fifth of the grain supply and, as it is the cheapest source carbohydrate, it probably is the food of the poor.[16] In the cases of China and Thailand, the linear programming solutions are on a knife edge. If the price of maize flour is increased by 1%, the linear programming solution for China for the reduced basic model flips to a rice based diet with 121 kg of rice, 87 kg of maize flour, 41 kg of fish, 15 kg of oil, and 40 kg of cabbage. A 1% increase in the price of maize in Thailand likewise shifts the same linear programming solution to 121 kg of rice, 18 kg of maize flour, 24 kg of beans, 14 kg of beef, 17 kg of palm oil, and 38 kg of cabbage. This is in accord with traditional consumption. The increase in cost from these changes is negligible.

In Bangladesh, the wheat based diet reflects globalization and peculiar features of 2011. While Bangladesh is a rice growing country, it is open to international trade, so the price structure, at least in the port cities, reflects the world pattern. In 2011, wheat was cheaper, then rice, and in 2015 wheat was again the cheaper grain.[17] The urban poor responded to these price changes by changing their consumption. “More affordable prices of wheat flour have increased consumption of wheat-based food. It appears that a section of low-income people have shifted to wheat because of a price gap, said Abul Bashar Chowdhury, chairman of BSM Group, a Chittagong based-commodity importer.” (Parvez 2015). In the countryside, wheat was not readily available, and the cheapest diet was rice-based and cost 14% more.

Mr. Chowdhury’s observation probably has considerably broader significance. One reason why linear programming works well in Africa may be the poor transportation infrastructure of that continent. With high shipping costs, Africa is divided into distinct food districts with distinct price structures that reflect local supply conditions. Linear programming choses the characteristic local cereal because it is cheap. Asia has much better infrastructure and is more closely integrated into world markets. As in Bangladesh, prices are less likely to reflect local supply conditions, so the linear programs are less likely to replicate the traditional low cost diets. This is not a failing, however, but a reflection of the

[16]See the websites of the FAO *Food Balance Sheets* and the *Food Fortification Initiative*.

[17]See website FAO, *Food Price Monitoring and Analysis Tool*.

evolution of the world economy. The diets of the well-to-do have become more cosmopolitan as the their countries have become more globalized and so have the diets of the poor. As transport costs approach zero, the diets of the poor will become the same the world over.

Linear programming solutions have also been obtained for a sample of rich countries in Europe and North America–the USA, UK, France, and Lithuania. As noted previously, the solutions look like Stigler diets, although with less beans and more oil. They do not describe what many people actually consume. Wheat flour, rather than maize, is the principal carbohydrate.

Despite initial anomalies with some of the Asian countries, linear programming does explain many features of the consumption of the poor in the developing world. The reduced basic and basic models explain the structure of their diets–the vegetarianism, the leading role played by carbohydrates, and the supporting roles played by oil, milk or fish, and vegetables. Usually, linear programming identifies the grain that is the staple in each country. The main discrepancy between the linear programming solutions and the diets of the poor is that the latter have a greater variety of vegetables, although not a greater total volume. The prices of many vegetables are similar, so variety in that regard can be increased at little cost. In every other respect, the linear programming diets are monotonous, but so is the food of the poor.

Linear Programming models and the World Bank Poverty Line

We now consider the relationship between the linear programming approach to diet and the World Bank poverty line. First, we have to add the non-food costs to the cost of the diets implied by the linear programs. I will refer to this total as the linear programming poverty line (LPPL). Then we can see how the LPPL relates to the World Bank poverty line. Do they equal each other? If so, with what nutritional requirements? The answer is that the same range of requirements that explains the behaviour of the poor–the reduced basic and the basic models–rationalizes the $1.90 per day poverty line.

Table 11 contrasts the LPPL, which is expressed in local currency since the prices are in local currency, for the range of diets with the $1.90 poverty line converted into the local currency of each of the twenty countries. The local currency equivalent of the $1.90 poverty line is the World Bank's conversion or my estimate of the conversion.[18]

The relationship between the various linear programming poverty lines and the World Bank's line is different for the OECD/Eurostat countries (USA, UK, France, Lithuania, Mexico, and Turkey) than for the developing countries. Table 11 shows the ratio of the linear programming poverty lines for the five sets of nutritional requirements considered previously relative to the World Bank poverty line for each country. For the rich countries,

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[18]*World Development Indicators* 2015, Table 2.8, Poverty Rates at International Poverty Line. Values for some countries not shown in the Table were supplied by Shaohua Chen of the World Bank, and I am grateful for her help. The values of the poverty line in local currencies equal $1.90 multiplied by the Global Aggregated PPP for individual household expenditure by household in the ICP2011 spreadsheet; however, the official value for Algeria differs from this calculation. Official values of the poverty line in local currency have not yet been finalized for Bangladesh, Egypt, Myanmar, and Zimbabwe. Table 12 uses a value for the line equal to $1.90 multiplied by the household expenditure PPP as just described. These values are obviously subject to revision.

the line implied by the full course model with all the vitamins and minerals is closest to the World Bank line. All of the other models imply lines that cost less than the World Bank line.

However, for the developing countries the relationship is different. For these countries, the line implied by the full course model is, on average, 35% more expensive than the World Bank line. At the other extreme, the LPPL corresponding to the 1700 calorie model is much below the World Bank poverty line, as is the line implied by the CPF model. These solutions average 54% and 76% of the World Bank poverty line. The lines that are closest to the World Bank line are the ones corresponding to the reduced basic model (which exactly equals the World Bank line on average) and the basic model (at 111% of the World Bank line). We can disaggregate further: The reduced basic model implies poverty lines that are closest to the World Bank line for economies where rice is the staple, while the basic model implies lines that are closest for the other economies.

Table 12 reverses the calculations in Table 11 and shows the dollar equivalents of the linear programming poverty lines by converting them at the PPP exchange rate for individual consumption. For poor countries the LPPL computed with reduced basic and basic requirements average near $1.90 per day. From the programming point of view, the meaning of the $1.90 line is that it corresponds to a life style defined by the corresponding quality of nutrition. However, the table also shows significant discrepancies between the countries in their dollar equivalents. In the case of Sri Lanka, for instance, the dollar equivalent of the reduced basic requirements costs $2.51 per day rather than $1.90. When $1.90 is PPP'd into local currencies and used as the international poverty line, the resulting measures of the number of poor are not comparable because different nutrition standards are implicit in different countries. In the case of Sri Lanka, for instance, there are more poor people than $1.90 implies, while for Turkey where the same line costs $1.39, there are fewer poor people.

This correspondence leads to the important general conclusion that, in developing countries, the basic and reduced basic models explain the lifestyles of the poor and also imply costs that correspond on average to the World Bank poverty line. The World Bank poverty line and the consumption of the poor are both rationalized by the same linear program.

Poverty Lines and Incomes

The linear programming poverty lines are an annual cost of subsistence. They can be used as a deflator to measure real income. One form of the calculation would be the welfare ratio–that is the ratio of annual income to the cost of maintaining a family at the LPPL (Blackory and Donaldson 1987). The latter equals the LPPL multiplied by the size of the family. This is interesting in its own right, and also because it provides another check on the reality of the poverty line. The income of 'a poor person' ought to be less than or equal to the poverty line.

ICP2011 provides some evidence to explore this possibility since it includes wages and salaries that correspond to components of gross national expenditure like construction, transportation, education, health, domestic service, and government employment. Unfortunately, there are no agricultural incomes in ICP2011; however, incomes are reported for general labourers, cleaners, caretakers, cooks, and drivers. All earned low incomes, and the general labourers were at the skill level that ought to have earned at the poverty line in a poor country, if not below it. ICP2011 reports annual salaries for all of these except labourers for whom an hourly rate is reported. Assuming the labourers worked 2000 hours per year, Table 13 summarizes their welfare ratios as well as those of the cleaners, caretakers, cooks, and drivers. The table also assumes a family included six people, ie six people were supported by the earnings of one.

Incomes look appropriately low and poverty correspondingly widespread by this measure in much of the world. In sub-Saharan Africa, Myanmar, and Vietnam, most ratios were below one. These workers were poor. General labourers also had ratios below one in Thailand and Indonesia and barely exceeded one in India and Bangladesh. (The ratio for labourers in Liberia is so low as to raise a question about the data.) It took the earnings of more than one person to support a family in most of these groups.

The balance between income and subsistence was more favourable amongst other groups in the developing world. Welfare ratios range between 2 and 4 in most or all of the occupations in Algeria, India, Indonesia, and China.

Welfare ratios increased with income. In Turkey and Mexico, low skilled occupation welfare ratios were in the range of 4-6. Lithuania performs particularly poorly in this regard given its national income. In the UK, USA, and France, low skilled workers earned 15 to 25 times subsistence. Ratios for these countries might in reality be higher since their family sizes are smaller.

While the 'male bread winner' model of the family that underlies these calculations may well be simplistic, it does highlight some of the implications of poverty and affluence. The results confirm that the LPPL and the World Bank poverty line are realistic standards for poverty measurement.

Poverty Purchasing Power Parity

One of the contentious issues that has arisen with the World Bank Poverty line is the exchange rate to use in converting the dollar value of the line into local currencies. The standard World Bank procedure is to use the purchasing power parity (PPP) exchange rate for individual consumption expenditure by households. The spending pattern of the poor differs from the average pattern, and the question is whether a poverty purchasing power parity (PPPP) exchange rate would give a different conversion.

This issue can be explored with the LPPL's calculated in this paper. In the dual formulation of the standard model of consumer choice, the solution to the problem of minimizing the cost of reaching a specified utility level is the expenditure function, which expresses that cost as a function of the prices of the consumer goods and the specified utility level. If the expenditure function is evaluated at two sets of prices, the ratio of the costs in the two cases is the 'true cost of living index': It indicates the relative change in spending needed to compensate the consumer for the differences in prices by keeping him or her at the same level of utility. The solution to the linear programming problem does not give an explicit expenditure function, but it does indicate the cost of meeting the specified requirements at the given prices. The ratio of the costs of meeting the specified requirements at two sets of prices is the linear programming analogue to the true cost of living index. Consequently, when the nutritional requirements are set at poverty levels, that ratio is the true poverty purchasing power parity (PPPP) exchange rate.

It should be noted that the ratio of the costs in the 'true linear programming cost of living index' is not an index number of the orthodox sort. The numerator and the denominator need not have any items in common, for instance. Uniform requirements ensure comparability as the consumption pattern shifts in response to price differences.

Table 14 shows the linear programming PPPPs for the various levels of nutritional requirements and the PPP of individual consumption, and Table 15 shows that former relative to the latter. The averages at the bottom of Table 15 make two general points. First, the PPPPs for the 1700 calorie models are greater than the PPPP for more adequate diets. Setting the 1700 calorie models aside, the poverty PPPs for the OECD and Eurostat countries average out at close to the average PPP for individual consumption. That, however, is not the case for the poor countries. Their poverty PPPs average out at about 75% greater than the individual consumption PPPs. This result parallels that in Table 12 where it was shown that it costs much less to purchase any level of nutrition in a rich country than in a poor country when the currency conversions are done using the individual consumption PPPs.

Conclusion

In this paper we have proposed that poverty lines can be defined by specifying a basic needs basket. That is an old idea. The novelty is using linear programming to specify the food component of basic needs. While the diet problem was the first problem ever formulated as a linear programming problem and remains a classic for teaching purposes, the common view amongst economists is that it does not describe anyone's behaviour. While that belief is certainly appropriate for rich people, we have argued that it is not correct for the 'absolute poor'. When people are on the margin of survival, their needs take precedence over their desires, and their behaviour is governed by linear programming. This statement is not unambiguous, however, for a range of nutritional requirements can be imposed on the diet problem. We have argued that the 'reduced basic' and 'basic' requirements–those which supplied adequate amounts of calories, protein, fat, and the vitamins and minerals needed to prevent anaemia, beri-beri, pellagra, and scurvy–imply diets that describe the main features of the diets of the poor. Those diets are based around common grains–not necessarily the cheapest–legumes, a little milk or fish, oil, and vegetables. When minimal housing and clothing and fuel adequate for tropical conditions are included, the cost of these linear programming poverty lines (LPPL) works out in 2011 at about $1.90 per day. The LPPL is a new basis for the World Bank Poverty Line.

The LPPL has both a subjective and an objective basis. On the subjective plane, the LPPL is consistent with the behaviour of poor people in developing countries. In that sense, they acquire a voice, and their behaviour becomes the basis of the poverty line. We noted at the outset that the subjective basis of the data points in the original Ravallion, Datt, and van der Walle (1991) paper were the views of the social scientists who came up with the poverty lines for poor countries in their data set. We can now see more clearly what the social scientists thought poverty meant: It meant a low cost, mainly vegetarian, diet that provided enough nutrition for society to function and reproduce and which was generous enough to keep the main deficiency diseases, which were common early in the twentieth century, at bay. Income also had to be adequate to provide the minimal clothing, fuel, and shelter needed in the tropics where most of the world's poor live.

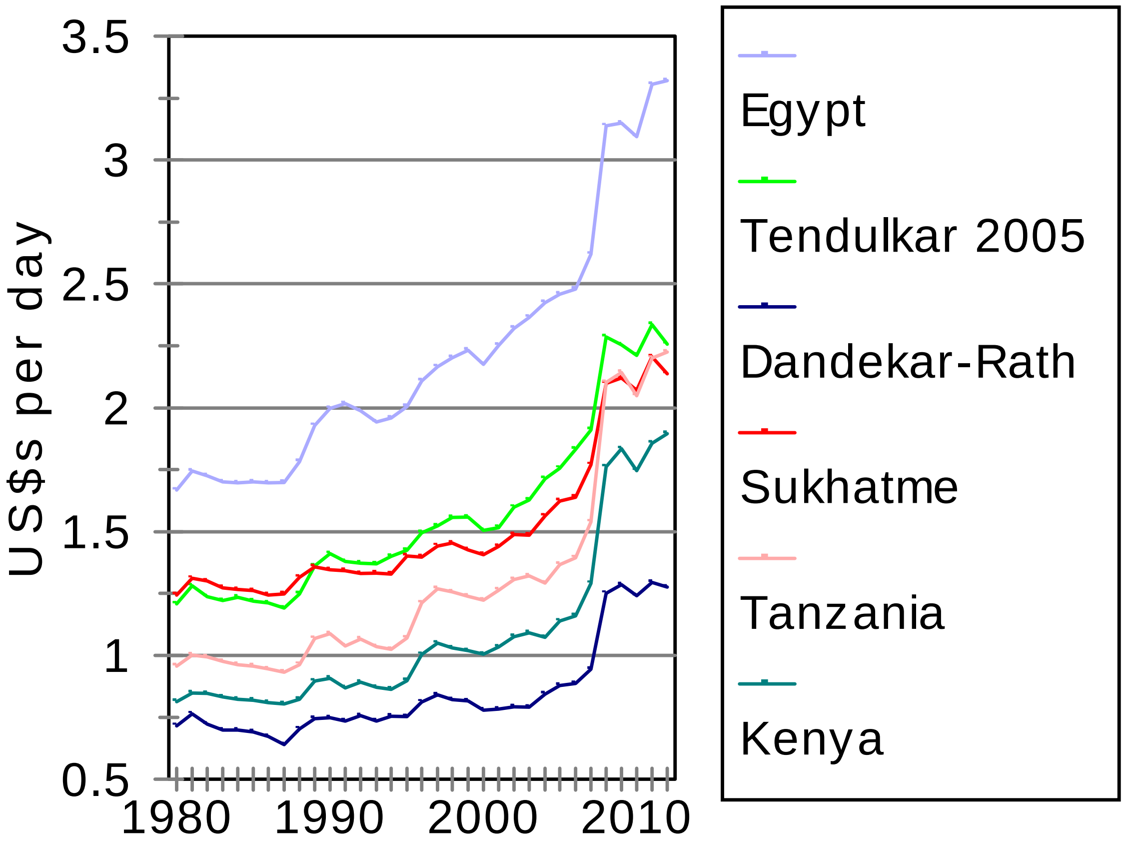
We argued in the introduction that an international poverty line should satisfy five conditions. The linear programming poverty line meets all of them. First, the line should have a clear meaning related to survival. The LPPL meets this condition since it is defined in terms of the food, fuel, clothing, and shelter requirements to ensure social reproduction and defence against the main deficiency diseases. Second, the line should represent a constant standard across time and space. This requirement is met by imposing the same nutritional requirements in all cases. A qualification, however, is in order regarding food, fuel, and shelter–greater requirements would be needed to ensure comparability between the tropics and cold climates, and the research to set those requirements has not yet been done. Third, the poverty line should respond to local prices and any other pertinent local factors. Local prices determine the solution to the linear programming along with the nutritional requirements. Fourth, the poverty line should avoid intractable index number problems. There are no index number problems with the linear programming approach since the solutions to the diet problem are in local prices and the non-food requirements are also costed with local prices. Comparability across countries and over time is guaranteed by using the same requirements everywhere–not by PPP. Fifth, the poverty line should require only readily available information. An ICP data set without missing values and including a fuller range of cheap foods and accommodation costs would be do the job.

The linear programming poverty line provides a direct connection between the value of the line and its meaning in terms of human health and social reproduction. Using the LPPL provides a more transparent approach to poverty measurement than existing World Bank procedures. On average, LPPL gives the same answer for poor countries, although there are differences from country to country.

In rich countries, the USA in particular, nutritional requirements can be met less expensively than in poor countries when the currency conversions are done at the individual consumption PPPs. Poverty PPPs, therefore, differ significantly from individual consumption PPPs. Discrepanices between index numbers are bound to create doubt about the significance of the World Bank Poverty Line. These hornets nests can be avoided by using nutritional requirements rather than index numbers to establish comparability between countries and over time.

Figure 1

Poverty Line Baskets priced in US dollars



note: US dollar prices from BLS website

Figure 2

Poverty Line Baskets priced in Indian rupees and converted to US$s at PPP

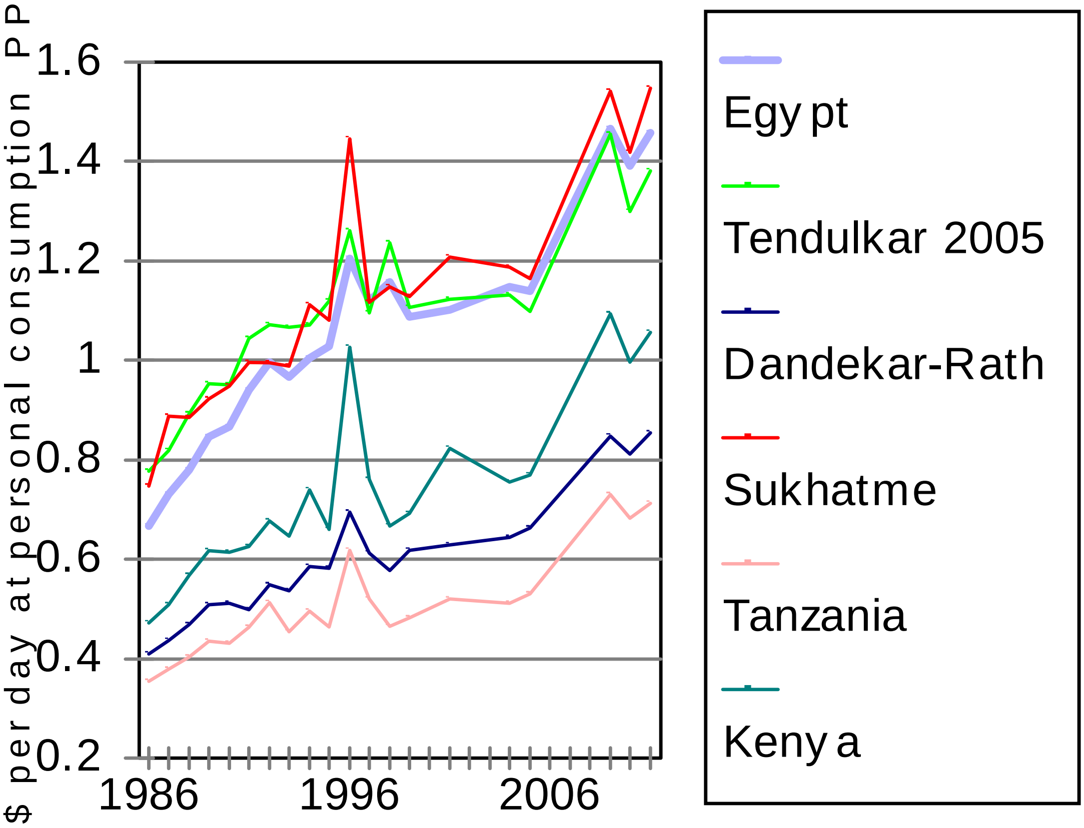
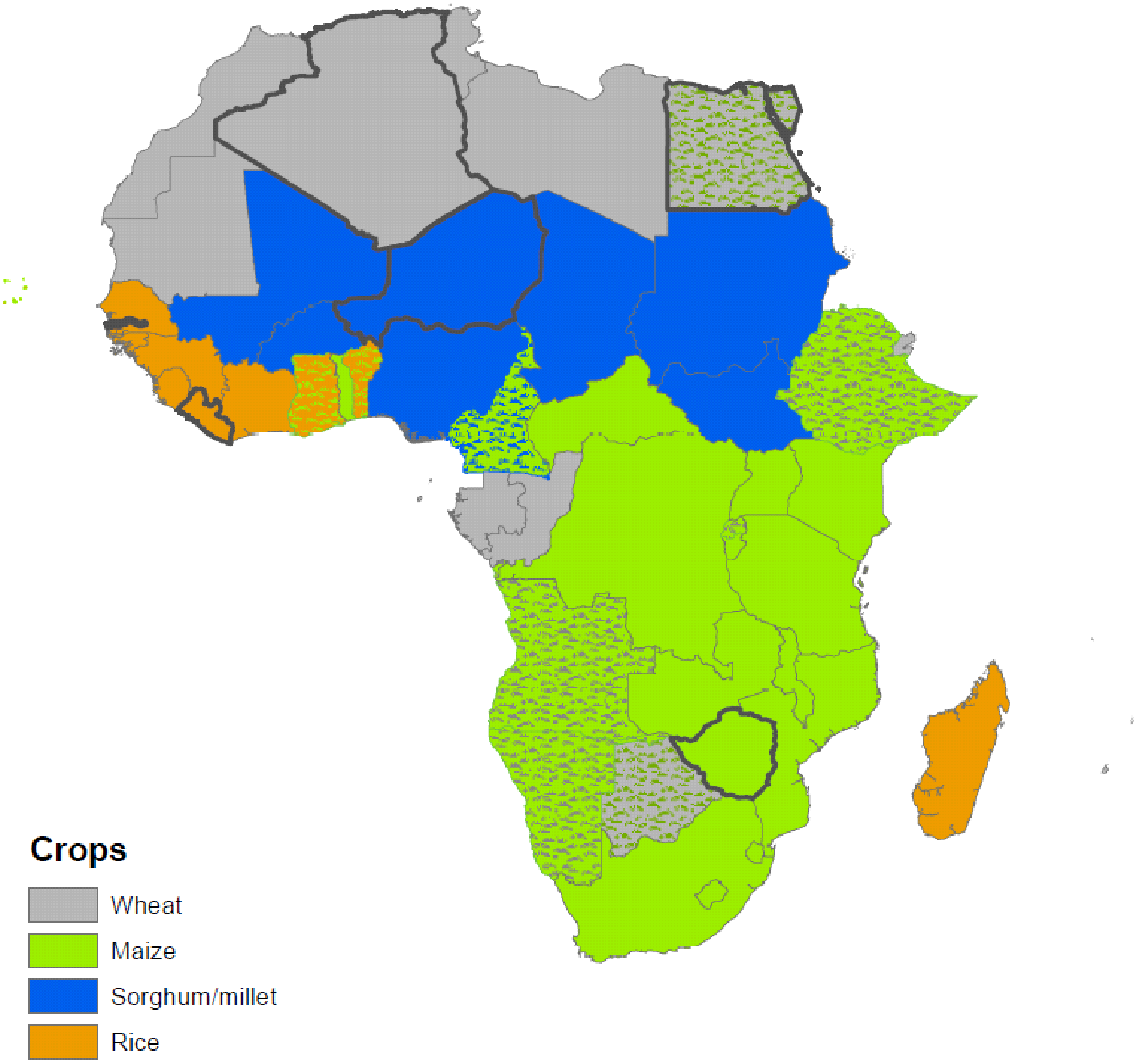


Figure 3

Principal and Secondary crops in Africa and countries for which LP diets computed



The background colour is the main crop and the icon is the secondary crop.

Table 1

Some Modern Baskets underlying
the World Bank Poverty Line
(Kilograms per person per year)

	Egypt	Tanzania	Kenya
wheat	34.2		
maize	33.6	188.2	136.9
millet	1.1		
flour	44.7		
rice	22.7		
macaroni	54.2		
beans/pulses	20.9	37.6	58.7
meat	5.5		
poultry/fish	3.6		
eggs	3.4		
oil/fat/butter	7.8	5.4	
milk	3.4		
cheese	8.2		
potatoes	12.1		
onions	8.0		
tomatoes	13.7		
other veg/fruit	6.6		
sugar	14.8	11.47	
Kg food/head/year	298.5	242.67	198.6
Kcal/day	2114	2200	1715
food share	60%	75%	75%

sources:
Egypt–Radwan and Lee (1986, p. 83)for food consumption per adult equivalent, p. 84 for ratio of food to total, and p. 86 for ratio of people to adult equivalents. The quantity of beans and pulses were increased in proportion to the calories derived from the consumption of cooked beans and falafel, the quantities of which are not reported.
Tanzania–Jamal (2001, p. 38). This appears to be a published version of the source cited by Ravallion, Datt, van de Walle, and Chan (1991).
Kenya–Crawford and Thorbecke (1980, p. 316) for diet per adult equivalent and p. 318 and 319n16 for the ratio of people to adult equivalents.

Table 2

Indian Poverty Line Budgets

	Sukhatme	Dendekar-Rath	Tendulkar (implicit)
grain	147.10	204.67	122.52
starchy roots	16.79		
legumes/pulses	37.96	20.09	9.80
milk	73.37	14.60	29.07
oil	6.57	2.33	7.32
meat etc	2.56	1.54	7.92
fish & eggs	6.94		
sugar	18.25	6.69	8.1
salt & spices			2.96
fruit & veg	50.01		61.64
other food		2.38	17.04
intoxicants			1.78
clothing		7.91	
fuel & light		1.52	
miscellaneous		[1.3 R.]	
Kg food/head/year	359.55	252.3	268.15
Kcal/day		2311	1960
food share		79%	56%

Note: all food is kilograms/person/year. Clothing is metres of cloth, fuel & lighting is in millions of BTUs (derived from implicit consumption of kerosene). The 1.3 Rupees shown as 'miscellaneous' is the spending on miscellaneous items in NSS 138, Table 1.6.0 for 13-15 Rs. per person per month.

Table 3

1700 Calorie model diets
(kilograms per person per year)

	wheat flour	bread	rice	maize	millet	beans or lentils	oil
Niger							70
Zimbabwe					178		
Gambia					176		
Liberia				172			
Egypt					178		
Algeria	170						
Turkey					172		
India					172		
China							70
Thailand							70
Indonesia							70
Bangladesh							70
Myanmar							70
Sri Lanka				175			
Vietnam							70
Mexico	170						
Lithuania	170						
UK	170						
USA							70
France	170						

Table 4

Total weight of linear programming diets (kilograms per person per year)

	1700	CPF	reduced basic	basic	full course
Niger	70	187	278	325	389
Zimbabwe	178	210	299	333	336
Gambia	176	199	231	257	351
Liberia	172	186	217	232	335
Egypt	178	207	358	423	478
Algeria	170	200	264	262	392
Turkey	172	206	309	310	382
India	172	193	290	352	403
China	70	273	295	364	799
Thailand	70	193	238	251	296
Indonesia	70	193	233	243	335
Bangladesh	70	184	242	358	349
Myanmar	70	189	233	238	389
Sri Lanka	175	193	269	260	422
Vietnam	70	189	263	307	566
Mexico	170	195	284	284	321
Lithuania	170	195	257	519	579
UK	170	195	275	275	359
USA	70	195	278	278	310
France	170	195	287	473	395
average	132	199	270	317	409

Table 5

Number of items in linear programming diets

	1700	CPF	reduced basic	basic	full course
Niger	1	2	4	4	7
Zimbabwe	1	2	4	5	6
Gambia	1	3	5	6	7
Liberia	1	3	5	5	7
Egypt	1	3	5	5	6
Algeria	1	3	4	6	5
Turkey	1	2	5	5	5
India	1	3	5	5	5
China	1	2	4	4	6
Thailand	1	3	5	6	7
Indonesia	1	3	5	7	6
Bangladesh	1	3	5	5	6
Myanmar	1	3	6	6	7
Sri Lanka	1	3	5	5	5
Vietnam	1	3	5	7	8
Mexico	1	2	4	4	5
Lithuania	1	2	6	5	7
UK	1	2	4	4	7
USA	1	2	4	4	8
France	1	2	5	5	7
	1	2.55	4.75	5.15	6.35

Table 6

CPF diets
(Kilograms per person per year)

	wheat flour	bread	rice	maize	millet & sorghum	beans & lentils	milk	fish	eggs	cheese & beef	oil	potatoes	cassava	spinach cauliflower peanuts
Niger					167						20			
Zimbabwe				198							12			
Gambia				111	76						12			
Liberia			127			40					19			
Algeria	120	69									18			
Egypt				181		6					13			
Turkey	190										16			
India				145		33					14			
China				263							10			
Thailand				145		34					14			
Indonesia				145		34					14			
Bangaldesh	158					8					18			
Myanmar			127			43					19			
Sri Lanka			143			34					16			
Vietnam			127			43					19			
Mexico	177										18			
Lithuania	177										18			
UK	177										18			
USA	177										18			
France	177										18			

Table 7

CPF diet: vitamins and minerals relative to RDA

	iron	B12	folate	B1 (thiamin)	niacin	C
Niger	72%	0%	76%	121%	53%	0%
Zimbabwe	88%	0%	76%	168%	77%	0%
Gambia	88%	0%	77%	144%	69%	0%
Liberia	52%	0%	304%	107%	57%	12%
Egypt	32%	0%	78%	62%	47%	0%
Algeria	86%	0%	118%	168%	74%	2%
Turkey	101%	0%	81%	137%	188%	0%
India	80%	0%	296%	157%	67%	10%
China	90%	0%	100%	157%	93%	0%
Thailand	83%	0%	380%	138%	65%	11%
Indonesia	83%	0%	382%	138%	65%	11%
Bangladesh	34%	0%	118%	62%	40%	2%
Myanmar	78%	0%	263%	67%	42%	0%
Sri Lanka	61%	0%	355%	221%	157%	10%
Vietnam	78%	0%	258%	68%	42%	0%
Mexico	117%	0%	781%	337%	193%	0%
Lithuania	30%	0%	70%	52%	41%	0%
UK	117%	0%	781%	337%	193%	0%
USA	117%	0%	781%	337%	193%	0%
France	30%	0%	70%	52%	41%	0%

Table 8
reduced basic diets
(kilograms per person per year)

	wheat flour	bread	rice	maize	millet & sorghum	beans & lentils	milk	fish	eggs	cheese & beef	oil	potatoes	cassava	spinach cauliflower peanuts
Niger					142		70				16		50	
Zimbabwe				178			70				10			41
Gambia				30	131			7			13		50	
Liberia			108			40		7			18		44	
Algeria		226				9	70	0			14			40
Egypt				179					35		9			41
Turkey	93			81			70				13			53
India				148		22	70				12			38
China				203				41			11			40
Thailand				156		17		0		14	12			39
Indonesia				109		38		7			15		64	
Bangaldes	153							7			21			60
Myanmar			129			37		7			18			41
Sri Lanka			165			4			35		12			53
Vietnam			104			28		40			19		73	
Mexico	157						70				16			41
Lithuania	142					12		7			18	44		34
UK	157						70				16			31
USA	150						67				21			41
France	147					25	70				16			29

Table 9

Basic diets
(Kilograms per person per year)

	wheat flour	bread	rice	maize	millet & sorghum	beans & lentils	milk	fish	eggs	cheese & beef	oil	potatoes	cassava	spinach cauliflower peanuts
Niger					195		70				11		50	
Zimbabwe				148	65		70				9			41
Gambia				137	51			7			11		48	2
Liberia	141					21		7			16		47	
Algeria		248				59	70				13			34
Egypt	42			131					35		11			43
Turkey	104			70			70				13			53
India	22			197			70				10			53
China				275				41			8			40
Thailand	27			128		19				14	13			50
Indonesia	34			117		19		7			14		5	46
Bangaldesh	75		53					7			27			194
Myanmar			70			60		7			8		73	21
Sri Lanka			113			55			35		13			44
Vietnam	1			143				40			10		104	9
Mexico	157						70				16			41
Lithuania	48					26		7			19	418		
UK	157						70				16			31
USA	150						67				21			41
France	314					49	70				14			26

Table 10

Full course diets
(Kilograms per person per year)

	wheat flour	bread	rice	maize	millet & sorghum	beans & lentils	milk	fish	eggs	cheese & beef	oil	potatoes	cassava	spinach cauliflower peanuts
Niger				77	159		70				9		48	25
Zimbabwe				100	103		70				10			53
Gambia					280			5		7	7		11	41
Liberia	87	122						7			6		29	83
Algeria		220				49	118				12	43		37
Egypt		52		128					35		10			167
Turkey	139			32			70				13			128
India	31			134			70				11			157
China				188					19	6	10			576
Thailand	48			86			46		0	5	11			94
Indonesia	12	16		158				7			13			130
Bangaldes	22	10	117					7			21			172
Myanmar			99			31		7			12		54	186
Sri Lanka			152			8			35		12			215
Vietnam	1			97			12		30		11		397	20
Mexico	0			183			70				11			57
Lithuania	0			64		18	37		42		12	390		15
UK	72					69	70				16	93		39
USA	44	39		48		44	67				15			53
France	101	29				72	141				13			40

Table 11

linear program poverty line relative to World Bank Poverty Line

	1700 cal	CPF	reduced basic	basic	full course
Niger	33%	46%	74%	80%	96%
Zimbabwe	33%	42%	79%	84%	90%
Gambia	44%	56%	67%	70%	111%
Liberia	77%	99%	118%	137%	163%
Egypt	71%	89%	130%	135%	156%
Algeria	57%	68%	105%	138%	160%
Turkey	32%	49%	74%	74%	86%
India	54%	74%	94%	102%	115%
China	43%	68%	87%	99%	151%
Thailand	60%	100%	124%	137%	153%
Indonesia	50%	75%	86%	90%	108%
Bangladesh	48%	68%	79%	91%	95%
Myanmar	58%	90%	105%	123%	150%
Sri Lanka	67%	95%	132%	152%	175%
Vietnam	54%	94%	120%	139%	171%
Mexico	31%	41%	56%	56%	63%
Lithuania	46%	56%	78%	103%	134%
UK	23%	30%	44%	44%	86%
USA	18%	42%	58%	58%	89%
France	24%	29%	53%	70%	89%
non-OECD	54%	76%	100%	113%	135%
OECD	29%	41%	60%	68%	91%

Table 12

Linear Program Poverty Lines converted to US dollars per day at PPP

	1700 cal	CPF	reduced basic	basic	full course
Niger	0.62	0.87	1.41	1.52	1.82
Zimbabwe	0.64	0.83	1.56	1.65	1.77
Gambia	0.84	1.07	1.27	1.34	2.11
Liberia	1.50	1.92	2.28	2.65	3.17
Egypt	1.36	1.70	2.48	2.59	2.98
Algeria	1.08	1.30	2.00	2.62	3.03
Turkey	0.61	0.92	1.39	1.39	1.62
India	1.02	1.40	1.80	1.93	2.19
China	0.82	1.29	1.65	1.87	2.87
Thailand	1.14	1.89	2.35	2.60	2.91
Indonesia	0.96	1.42	1.64	1.70	2.04
Bangladesh	0.95	1.34	1.57	1.79	1.86
Myanmar	1.03	1.60	1.87	2.20	2.69
Sri Lanka	1.28	1.81	2.51	2.88	3.33
Vietnam	1.03	1.80	2.27	2.64	3.25
Mexico	0.60	0.77	1.06	1.06	1.20
Lithuania	0.87	1.07	1.48	1.97	2.56
UK	0.45	0.56	0.84	0.84	1.64
USA	0.34	0.81	1.11	1.11	1.70
France	0.45	0.55	1.00	1.34	1.69
non-OECD	1.02	1.45	1.90	2.14	2.57
OECD	0.55	0.78	1.15	1.28	1.73

Table 13

Full Year Earnings relative to LPPL for a family of six

	general labourer	cleaner	caretaker	cook	driver
Niger	0.59			1.75	1.62
Zimbabwe	1.23				
Gambia	1.33	0.61	0.61	0.67	0.70
Liberia	0.25	0.53			0.66
Egypt	1.92	1.33	2.09	1.10	1.33
Algeria	1.28	2.25	1.70	2.95	2.26
Turkey		7.14	5.78		5.92
India	1.05	2.21	3.78	2.90	2.90
China	2.98	2.66	4.62	4.61	6.07
Thailand	0.83			3.40	
Indonesia	0.90	3.36	3.80	3.53	3.54
Bangladesh	1.08	1.58	1.58	1.64	1.77
Myanmar	0.67	0.55	0.57	0.61	0.65
Sri Lanka	0.76	1.19	0.97	1.25	1.16
Vietnam	1.13	0.53	0.84	0.85	0.80
Mexico		5.07	4.34		4.68
Lithuania		2.95	3.69		4.30
UK	24.45	15.68	15.47		15.23
USA	28.30	16.51	21.49		14.19
France		21.03		16.77	16.77

Table 14

Poverty Purchasing Power Parity Exchange Rates

	1700 cal	CPF	reduced basic	basic	full course
Niger	412.50	247.14	291.83	314.97	244.61
Zimbabwe	1.00	0.55	0.76	0.80	0.56
Gambia	26.47	14.43	12.39	13.08	13.43
Liberia	2.47	1.35	1.17	1.36	1.06
Egypt	7.13	3.81	4.04	4.22	3.17
Algeria	99.99	51.14	57.59	75.33	56.74
Turkey	2.08	1.34	1.46	1.46	1.11
India	44.64	26.06	24.34	26.17	19.33
China	8.79	5.93	5.52	6.26	6.24
Thailand	42.75	30.17	27.34	30.19	22.00
Indonesia	11383.29	7191.80	6064.57	6306.80	4926.88
Bangladesh	68.76	41.28	35.19	40.26	27.26
Myanmar	830.07	547.20	467.55	549.26	436.31
Sri Lanka	157.54	94.75	95.79	110.08	82.85
Vietnam	22964.31	16983.53	15662.94	18194.14	14609.29
Mexico	15.53	8.57	8.60	8.60	6.31
Lithuania	4.52	2.36	2.39	3.18	2.69
UK	0.98	0.53	0.57	0.57	0.73
USA	1.00	1.00	1.00	1.00	1.00
France	1.14	0.60	0.80	1.06	0.88

Table 15

Linear Programming PPPPs relative to Individual Consumption PPP

	1700 cal	CPF	reduced basic	basic	full course
Niger	1.80	1.08	1.28	1.38	1.07
Zimbabwe	1.87	1.03	1.41	1.49	1.04
Gambia	2.44	1.33	1.14	1.21	1.24
Liberia	4.35	2.38	2.06	2.40	1.86
Egypt	3.96	2.11	2.24	2.34	1.76
Algeria	3.15	1.61	1.81	2.37	1.79
Turkey	1.79	1.15	1.26	1.26	0.95
India	2.98	1.74	1.63	1.75	1.29
China	2.38	1.60	1.49	1.69	1.69
Thailand	3.33	2.35	2.13	2.35	1.71
Indonesia	2.78	1.76	1.48	1.54	1.20
Bangladesh	2.77	1.66	1.42	1.62	1.10
Myanmar	3.01	1.98	1.70	1.99	1.58
Sri Lanka	3.73	2.24	2.27	2.61	1.96
Vietnam	3.01	2.23	2.05	2.39	1.92
Mexico	1.74	0.96	0.96	0.96	0.71
Lithuania	2.53	1.32	1.34	1.78	1.51
UK	1.30	0.70	0.76	0.76	0.97
USA	1.00	1.00	1.00	1.00	1.00
France	1.30	0.68	0.91	1.21	1.00
non-OECD	2.97	1.79	1.72	1.94	1.52
OECD	1.61	0.97	1.04	1.16	1.02

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Notes on the linear programming

The following foods were represented in the objective function (equation 1) in the linear programs:

wheat flour, wheat bread, rice, maize flour, oatmeal, beans, eggs, cheese, chicken, milk, meat, fish, butter, margarine, vegetable oil, white sugar, potatoes, tomatoes, cucumbers, cabbage, sweet potatoes, carrots, onions, cauliflower, spinach, ginger, garlic, roasted peanuts, avocado, mushrooms, cassava, tofu, alcohol

In addition, the programs for Africa also included millet, millet flour, red sorghum grains, yellow maize grains, and white maize grains

When prices for items in this list were not available in a country, they were excluded from the choice options in the linear program.

Generally, the nutritional composition of foods are reported per 'edible portion.' In the requirement inequalities in the linear programs (equation 2), the nutritional compositions reported in the databases like the USDA *National Nutrient Database* were multiplied by the percentage of the food that is edible (ie allowing for bones, etc), so that the solution of the linear program was the weight of food purchased at the prices specified in ICP2011.

The ICP contains many foods, most of which are clearly too expensive to be chosen by the linear program. For instance, thirteen different kinds of fresh fish or seafood are listed in the core price list of ICP2011, although not all prices are available in all countries. The fish that was cheapest in terms of its protein content (allowing for losses in bones, fins, etc) was used in the linear program. This was usually mackerel or tilapia or carp. Similar selections were made for meat in terms of the cost of protein, bread in terms of the cost of calories, and alcohol in terms of alcohol content. The African regional price list contains a great variety of local alcoholic beverages, which were also investigated to find the cheapest source of alcohol.

Sometimes ICP2011 reported prices for goods that could not have been widely available. Thus, there is a price for mackerel in Zimbabwe. At that price, mackerel is included in the least cost diet. It is so implausible, however, that mackerel is widely available in Zimbabwe that it was excluded from the choice options for that country. Similar exclusions were made in some other cases when it was deemed that the food in question was not widely available.

Online data sources

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