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Kolleen Rask
College of the Holy Cross, krask@holycross.edu

Norman Rask

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Department of Economics
College of the Holy Cross
Box 45A
Worcester, Massachusetts 01610
(508) 793-3362 (phone)
(508) 793-3708 (fax)

http://www.holycross.edu/departments/economics/website

Measuring Food Consumption and Production According to Resource Intensity: The Methodology Behind the Cereal Equivalent Approach

By
Kolleen Rask[†]
College of the Holy Cross
and
Norman Rask[††]
The Ohio State University

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Abstract

The production of food is one of humanity's fundamental and most critical endeavors, yet our understanding of its impact on limited global resources is not well developed. Food production supplies a basic human need, provides important employment for millions of the world's poor, and generates significant export income for some countries, while using up valuable foreign exchange reserves for others. On the demand side, as population grows, demand for food grows commensurately. Even more importantly, as incomes grow, the per capita demand for food grows, and studies have shown that diet changes related to rising incomes result in a five-fold increase in food consumption per capita when measured in terms of resource use, or cereal equivalents. Following the publication of those studies, the authors received requests to clarify the calculation of specific cereal equivalent values. The purpose of this paper is to respond to these requests by detailing the methodology employed in the previous studies in order to allow other researchers to use this technique in their own work. We specify the required datasets, the individual calculations by food category, the adjustments necessary to measure country self-sufficiency in food, and the impact of GDP per capita on disaggregated food consumption measured in this way.

JEL Classification Codes: O13, Q18

Keywords: economic development, food consumption, agricultural self-sufficiency

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[†]Kolleen Rask, Department of Economics, Box 8A, College of the Holy Cross, Worcester, MA 01610-2395, 508-793-2768 (phone), 508-793-3708 (fax), krask@holycross.edu

[††]Norman Rask, Department of Agricultural, Environmental, and Development Economics, 242 Agricultural Administration, 2120 Fyffe Road, Columbus , Ohio 43210, 614-247-6957 (phone), 614-292-0078 (fax), rask.1@osu.edu

1. Introduction

The production of food is one of humanity's fundamental and most critical endeavors, yet our understanding of its impact on limited global resources is not well developed. Food production supplies a basic human need, provides important employment for millions of the world's poor, and generates significant export income for some countries, while using up valuable foreign exchange reserves for others. On the demand side, as population grows, demand for food grows commensurately. Even more importantly, as incomes grow, the *per capita* demand for food grows, and studies have shown[1] that diet changes related to rising incomes result in a five-fold increase in food consumption per capita when measured in terms of resource use, or cereal equivalents. Following the publication of those studies, the authors received requests to clarify the calculation of specific cereal equivalent values. The purpose of this paper is to respond to these requests by detailing the methodology employed in the previous studies in order to allow other researchers to use this technique in their own work.

Food production and consumption may be measured in a variety of ways, most commonly in terms of either expenditures or caloric content. While these measures provide insights into many types of questions, they cannot speak to the issue of resource use. For example, as incomes rise, an increasing proportion of food expenditure reflects non-food costs, such as marketing, packaging, and convenience. The purpose of creating cereal equivalent conversion factors is to provide for all types of food a single numeraire that captures the most basic food-related resource embodied in the food, namely, the land itself. Using cereals such as corn for the common denominator allows us to consider the impact on the land of both the direct and the indirect consumption of food[2] (cereals such as corn, wheat, barley, etc. are also principal feed inputs to livestock product production, and therefore are also consumed indirectly by humans). For example, when we eat a measure of corn, we need only consider the yield per acre to understand the impact on land resources. However, when we eat an identical measure of beef, we must consider our indirect consumption of cereals (grains); in other words, we must account for the consumption of grains by the animal itself, with adjustments for maintaining a breeding herd and so forth. In terms of resource use, then, consumption of a measure of beef (carcass weight) is shown to be equivalent to direct consumption of 19.4 measures of corn equivalents. For this reason, diets based on livestock products are highly inefficient users of the land, relative to diets based on direct vegetable and cereal consumption.

The focus on land is important, as land is ultimately the limiting factor in food production. Water, chemicals, mechanization, and technology can be brought to the land to enhance its productivity, but it is difficult to create more arable farmland. Certainly examples of created land exist in places such as the Netherlands, but they represent a tiny percentage of global farmland. Indeed, in many ways productive arable land is decreasing as a result of aquifer depletion, reservoir siltation, land erosion, and urbanization. The task at hand is to

[1] See Rask and Rask (2011) Rask and Rask (2006), Rask and Rask (2004).
[2] See Yotopoulos (1985).

increase food productivity sufficiently on the limited farmland to meet the rising demand for food based on both diet change (due to higher incomes) and population growth.

High income countries choose diets rich in livestock products, thereby consuming very high levels of cereal equivalents on a per capita basis. However, these countries currently constitute a small percentage of the world's population. Several developing countries with large populations, including China, India, and Brazil, are experiencing rapid economic development. As these populations continue to enjoy rising incomes, their diet changes will put even greater pressure on land resources. Understanding and quantifying this pressure, then, becomes critical.

2. Choosing the numeraire

The numeraire must adequately measure the many production and consumption items involved in the food production-consumption chain, and reflect both direct and indirect consumption in order to account for total use of the limited land resources. Cereals represent the most basic of foods produced on land and also become a major input to the production of livestock products, which in turn represent the principal source of increased food demand as incomes grow. Therefore, a cereal-based factor is developed to provide a single measure for all forms of food, and this measure in its per capita form allows us to compare country diets at various stages of economic development. We name this factor the *cereal equivalent* (CE)[3] and express it in tons per capita per year. Cereals and grains, as the basis of the measure, are assigned a CE factor value of one. In order to convert livestock products into these cereal equivalent values, we must sum the total quantity of all cereals and other feeds that are necessary inputs to the production of the livestock products. Vegetable products consumed directly are expressed in terms of cereal equivalents based on caloric content relative to an equal weight of cereals. A more detailed explanation of these conversions is provided below. Once each disaggregated type of food has been converted to its CE value, the total resource intensity of per capita diets across countries and across time can be calculated.

3. Data Sources and Conversions

The principal purpose in constructing the cereal equivalent data set is to provide a means to evaluate the relationship between country level per capita income and per capita food consumption. The three United States Department of Agriculture (USDA) data sources listed below supply the livestock enterprise feed requirements, livestock product sales, and meat conversion rates that were used to develop the CE coefficients. Additionally, three separate data sets with annual country level data were identified and form the basis for the analysis data set. The CE coefficient data sources and food consumption analysis data sets are the following:

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[3] Rask, 1991

3.1 Sources for constructing CE coefficients

United States Department of Agriculture (USDA), Economic Research Service, 1975. Livestock-Feed Relationships, National and State. Washington D.C.

United States Department of Agriculture (USDA), Economic Research Service, 1975. 10 years of annual livestock product marketing. Washington D.C.

United States Department of Agriculture (USDA), Economic Research Service, 1992 (updated 2013). Weights, Measures, and Conversion Factors for Agricultural Commodities and Their Products, Agricultural Handbook 697. Washington D.C.

3.2 Data sets for estimating CE consumption and self-sufficiency levels

The World Bank (WB) and Penn World Tables (PWT) provide data on annual country level gross domestic product (GDP) expressed in per capita purchasing power parity terms (GDPPPP) in constant US dollars;

The Food and Agriculture Organization (FAO) publishes FAOSTAT, which includes annual country level per capita consumption of specific individual and group food commodities (expressed in kilograms per capita per year and in kilocalories per capita per day) and annual data on product production, domestic supply (production minus exports plus imports, plus stock changes), feed, waste, and processed quantities (expressed in tons) by country, region, continent, and world groupings.

The above data sources and series differ in several important ways that require adjustments before melding into one data set for analysis. Differences include years and countries covered, weight and physical differences for some commodities in the level of processing between the consumption and the farm gate specifications (carcass weight vs. live weight, offal and fat consumption without animal source specification, etc.), and lack of data for some CE specifications (fish and other meat). We should note that nomenclature and data covering food items, countries, and years of coverage change periodically. Specific examples given in the following sections are current as of November 2014.

3.3 Country and year selection

In terms of data availability, annual food consumption data from the FAO are the most prevalent, extending for most countries from 1961. Annual GDPPPP data currently extend from 1980 for the World Bank series and from 1961 for the Penn World Table series, but they do not cover as broad a spectrum of countries as the FAO consumption series. There are some country-year gaps in the World Bank and PWT series, which, in some cases can be statistically bridged. Countries with no income data are eliminated from analysis.

3.4 The dataset for estimating CE conversion factors

A unique and comprehensive study of feed inputs to the livestock industry was conducted by the United States Department of Agriculture (USDA) from 1963-1974, and published in 1975. This study "estimates annual allocation of total available feed supplies to each livestock enterprise, including breeding herds as well as producing units, over a ten year period."[4] Of extreme importance is the inclusion in the study of *all* forms of feed, whether grain-based feed, protein supplements, or forages and pastures, with each type of feed converted to corn equivalents. In addition, the lengthy time span and comprehensive coverage allow for smoothing of anomalies due to individual production units or specific annual events.

The national input data (disaggregated by livestock product) are then compared with national output totals for each product to create an estimate of total feed resource use by quantity and type of livestock product. Further adjustments to the conversion factors are described below. This method provides a more reliable conversion estimate than could be gained by evaluating structured feeding trials, as normal production losses are naturally incorporated with our approach. For example, the typically quoted beef feed conversion rates (FCR) of 5-7 reflect only the feed conversion experienced in the feedlot with production animals typically exceeding one year of age. For each such feedlot animal there also exists a brood cow and a young calf to be included in next year's feedlot or to become a replacement brood cow. When feed for this breeding herd and replacement animals are factored in, the effective live weight CE increases to 11.7 as evidenced by the USDA study. Similarly, CEs for hogs and chickens reflect breeding herds as well, though higher reproductive rates and greater feeding efficiencies for these enterprises result in lower CEs than for beef. The USDA study does not present sufficient data to determine an individual CE coefficient for the FAO *mutton and goat meat* category. Therefore, since sheep and goats are ruminants, we assign the beef coefficient to this category.

Table 1. Live weight CE conversion factors.

Livestock Product	***Live weight CE conversion factor***
Beef	11.7
Pork	6.0
Chicken	3.2
Mutton and Goat	11.7

Despite its exclusive use of US data, the USDA data set does cover a wide range of production technologies and climatic conditions, including humid, arid, tropical, and temperate zones, and is therefore reflective of a large portion of global agricultural production. Furthermore, US agricultural efficiency was above the world average during this time period, but technology has improved tremendously since then. Using more recent US data, which we have confirmed are not available, would overstate global conversion efficiencies, while using this older data set should present a more realistic conversion picture for current global agriculture on an average basis. At any rate, the relative conversion factors developed by means of this methodology conform quite well to other

[4] Rask and Rask, 2011

measures, such as measures of environmental impact related to various agricultural production processes, as discussed below.

3.5 Adjustments to the livestock conversion factors

When the feed inputs for each category of livestock product (measured as corn equivalents and as determined by the USDA study) are combined with national output for each type of livestock product, initial estimates of the CE conversion factors result, as shown. However, the sample calculation above reflects the production of live-weight product, and therefore must be adjusted before comparisons with consumption data can be made, as country meat consumption data from the FAO are presented in carcass weight equivalents. Adjusting the live-weight measure for dressing weight percentage then creates a CE value that reflects the feed-resource inputs per consumable (carcass weight) livestock product. Average dressing weights for each livestock product are taken from the USDA publication "Weights, Measures, and Conversion Factors for Agricultural Commodities and Their Products" as follows: beef = .602, hogs = .724, and chickens = .723. We have no means to identify a feed input or dressing weight percentage for other meat products. We therefore assign a median carcass CE weight conversion factor of 12.0 for other meats.

Applying these dressing weights for each of the livestock meat products yields the following CE conversion factors:

Table 2. Carcass weight CE conversion factors. [5]

Meat Product	***Carcass weight CE conversion factor***
Beef	19.4
Pork	8.3
Chicken	4.4
Mutton and Goat	19.4
Other Meat	12.0

Two other livestock products, milk and eggs, are consumed directly. In the case of milk, the total feed input to dairy production is proportionally allocated to the various outputs of milk and beef, including slaughter calves, cull cows, and bulls. Similarly, the total feed input to egg production is allocated proportionately to eggs and spent hens. The CE factors for milk and eggs are given below.

Table 3. Livestock product CE conversion factors.

Livestock Product	***CE conversion factor***
Milk	1.2
Eggs	3.8

[5] New data have led to a slight adjustment in the CE conversion factors for meat products, compared to that reported in our previously published work.

At this point, we note that expressing food in terms of its cereal equivalent value specifically reflects a *corn* equivalence, following the USDA study. Information from the FAO reveals that the caloric content of the broader cereal category is identical to that of corn, based on 1999 US data, making this particular choice of measurement highly suitable. However, global averages do show a slightly lower caloric content per unit weight for corn than for the broader category of cereals.

3.6 Conversion factors for crop products

As the numeraire, cereals receive a CE conversion factor equal to one. Since other crops do not use cereal inputs in their production processes, these products are compared to cereals by means of relative caloric content of equivalent weights. For example, fruits provide a less concentrated source of calories per unit weight than do cereals, yielding a CE factor value less than one. Caloric content data for crops are obtained from FAOSTAT. They are given for each country-year and therefore will vary slightly across countries and through time. To give an example of the relative differences in caloric content for major crops, a sample is given below. Note that each individual country-year will vary from this general sample.

Table 4. CE conversion factors for sample crop products

Crop Product	***CE conversion factor***
Cereals	1.00
Fruits	0.14
Pulses	1.06
Starchy roots	0.25
Sugar, Sweeteners	1.08
Treenuts	0.77
Vegetable oils	2.72
Vegetables	0.08

Interestingly, these conversion factors have remained relatively unchanged over time, since our original calculations in the 1980s.

3.7 Foods that are not land-based

Finally, fish and seafood, harvested from oceans, rivers, and lakes, provide a higher level of food consumption similar to livestock products, but do not require land-based cereal inputs (except in some cases of fish farming) and were not considered in the USDA study. Further, when produced under 'farming conditions" fish and seafood are fed rations much higher in protein content then livestock rations (30-50% versus 10-20%). Carnivorous fish such as salmon and trout are typically fed fishmeal produced from harvested forage fish. Thus, in order to account for fish and seafood consumption in a total diet, an alternative use factor is employed in which the fish and seafood CE coefficient is assumed to have a conversion factor equal to the most efficient land-based livestock product, which is chicken. Since FAO fish consumption values are "fresh caught", not dressed weight, we use the chicken live-weight CE measure of 3.2.

This feed conversion ratio for fish of 3.2 is supported by input price data. Soymeal is a partial substitute for fishmeal, and current fishmeal prices are about 2.5-3 times higher than soymeal prices. Soymeal prices, in turn are about 4 times the price of corn, which is the principal ingredient in livestock concentrates. Adjustments are made based on the fact that fish are fed at a higher concentration level compared to livestock.

4. Comparison of our CE measure to the environmental literature

As we state in our *Food Policy* paper (2011), our review of the environmental impact literature reinforces our confidence in our CE conversion factors. For example, our CE coefficient for beef is 19.4 units of corn. Glendining (2009) estimates the environmental costs for wheat production and for beef production to range between £ 25 – £50 and £ 600 – £ 950, respectively (page 123), yielding a ratio of approximately 20 to 1 as well. Another study (Williams, 2006) estimates global warming potential for various types of food production. The ratios from this analysis (relative to wheat) are 19.7 for beef, 7.9 for pig meat, and 5.7 for poultry, again, strikingly similar to our own calculations.

5. Adapting FAOSTAT consumption data to CE coefficients

Livestock food product classification in the FAO data series is not completely compatible with our CE determinates. FAO meat consumption products, for example, are measured at an intermediate processing point between animal live weight and final consumption (carcass weight) minus offals and fat. Further, by-products such as offals and animal fat do not have specific animal identification. The animal fat category includes butter and cream, which are dairy products.

Accounting for these differences and melding these two classifications require some adjustments. FAO food supply consumption data is given in two broad categories, (1) crops and (2) livestock and fish. Each individual food item is expressed in two measures, kcal/capita/day and kg/capita/year. The crop category contains 74 individual food items and 13 aggregate food items. The livestock and fish category contains 27 individual food items and seven aggregate food items. In each category, the sum of the aggregate items equals the total per capita consumption for that category.

As noted earlier, our CE consumption variable is expressed in tons per capita per year. For crops we begin by assigning cereals a CE conversion factor equal to one. Since other crops do not use cereal inputs in their production processes, these products are compared to cereals by means of relative caloric content of equivalent weights. Thus, for food crops, we need a factor that simultaneously converts kcal/capita/day to CE/capita/year. We accomplish this by converting world cereal consumption in kg/capita/year to tons/capita/year (dividing by 1000) and dividing this value by world cereal consumption in kcal/capita/day.

For example, world cereal consumption in 2011 was 1296 kcal per capita per day and alternatively 147.2 kg per capita per year, yielding a conversion factor of (147.2/1000)/1296 = .0001136. Each crop food consumption category (kcal/capita/day) is then multiplied by this factor (.0001136) to provide its CE in tons/capita/year. This factor will vary slightly depending on the year or span of years chosen for its derivation.

Using this factor, we calculate the CE value for each aggregate crop food item and sum the aggregate food items to determine a total CE for crop products. Individual items can also be selected for analysis. For example, wheat and rice consumption display different trends across income levels.

Adapting CE coefficients to livestock and fish products is somewhat more complicated since, as noted above, each product has a different CE coefficient and the FAO product definition is not always compatible with the CE specification. For the livestock and fish product portion of consumption, we use the FAO kg/capita/year data. We use a combination of both the individual and aggregated series. The seven aggregated items are:

Animal Fats	Meat
Aquatic Products, Other	Milk-excluding butter
Eggs	Offals

In addition to the seven aggregated items, we use seven individual items to conform to our animal product CE coefficients. They are:

Bovine Meat	Mutton and Goat Meat
Butter, Ghee	Pig Meat
Cream	Poultry Meat
Meat, Other	

The needed adjustments are as follows. First, the FAO *animal fats* item contains both *butter* and *cream* as well as *animal fat*. We delete the *butter* and *cream* items from the *animal fats* category, reconstitute them to milk equivalents, and add them to the *milk* category. The factors for reconstituting butter and cream (on average, and based on USDA 1992 (updated 2013)) are given below.

Table 5. Milk product conversion factors.

Milk Products	***CE conversion factor***
Butter	21.8
Cream	10.0

Second, the meat aggregate is composed of the five individual meat items listed above, each with a different specific CE coefficient noted earlier, except for the *meat, other* category. The *meat, other* category is an unspecified minor source of consumption. We have no means to identify a feed input, so we assign a median value coefficient of 12.0 to the *meat, other* category.

Finally, *offals* and *animal fats* (now minus *butter* and *cream*) are allocated to the individual animal meat categories. FAO does not provide a manner to allocate these items. Therefore, we allocate both *offals* and *animal fats* to each of the four principal meat categories, *bovine meat*, *mutton and goat meat*, *pig meat*, and *poultry meat* based on their relative consumption quantities before applying the CE coefficients. For *poultry* we use the chicken

CE. Thus, in the final summation of *livestock* and *fish products* we have the following consumption variables:

Bovine meat (including a percentage of offals and animal fats)
Mutton and goat meat (including a percentage of offals and animal fats)
Pig meat (including a percentage of offals and animal fats)
Poultry meat (including a percentage of offals and animal fats)
Milk (including reconstituted butter and cream)
Eggs
Fish, Seafood
Aquatic products, Other

The last category, *aquatic products, other,* is a minor food consumption item that has no land-based CE derivation and no specific FAO product specification. Similar to fish, we assign an alternative-use CE value of 3.2. Note that final CE values are measured in *tons*/capita/year while the livestock consumption values are measured in *kg*/capita/year. Thus, in the analysis, the CE coefficient for *bovine meat* becomes .0194 not 19.4. Similarly, the *mutton and goat meat* coefficient becomes .0194, *pig meat* =.0083, *poultry meat* =.0044, *eggs* =.0038, *other meat* =.012, *milk* =.0012, *fish, seafood* =.0032, and *aquatic products, other* =.0032.

These eight *livestock and fish* variables are then summed and added to the crop summation to provide a measure of the total food CE.

6. Calculating Agricultural Self-Sufficiency Related to Food Commodities

The FAO data set under 'commodity balances' presents a number of categories for each commodity including production quantity, import quantity, export quantity , stock variation, domestic supply quantity, processed quantity, feed, seed, food, waste etc. The category *domestic supply quantity* includes *production* and accounts for changes in stocks, exports, and imports. Thus, individual commodity self-sufficiency can be calculated by dividing production quantity by domestic supply quantity for each specific commodity.

To calculate overall agricultural self-sufficiency requires two adjustments. First, to avoid double accounting, feed needs to be subtracted from both production quantity and domestic supply quantity for each commodity, since feed is an intermediate input to livestock production and has already been accounted for in the livestock CE. Secondly, each production quantity and domestic supply quantity (both minus feed) for each commodity needs to be adjusted for different resource use intensity before summing.

To accomplish this we multiply each production and domestic supply commodity (minus feed) by the appropriate CE coefficient, as determined above. In the case of cereals this factor is one. Corresponding factor values for livestock products are 19.4 beef, 8.3 for pork, etc. For crop products we establish a factor ratio relative to cereals by dividing the specific crop product expressed in kcal/capita/day by its kg/capita/year value, as discussed above, and then divide this by the corresponding value for cereals. This establishes the correct relationship between each individual commodity and the value of one for cereals. All production quantity CE values so determined are then summed and divided by the sum of all domestic supply quantity CE values to determine an overall agricultural self-sufficiency related to food agricultural commodities.

In some special cases, for example when a food agricultural commodity has a large non-food processing component as part of its overall use, additional adjustments (above the feed adjustment mentioned previously) may be needed to determine agricultural self-sufficiency for a specific country.

7. Income measurements

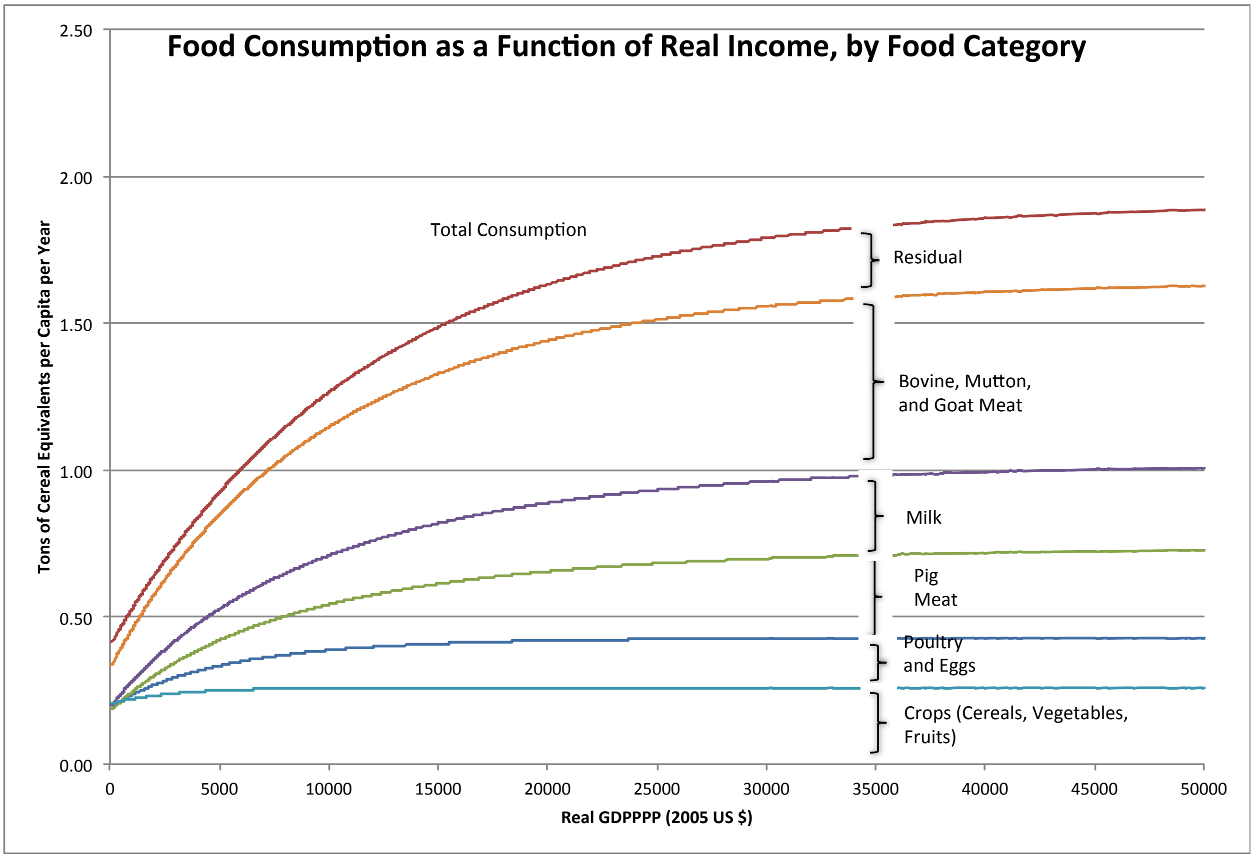
Given the importance of using real income measurements that are commensurate across countries and time, we try to acquire all data from one source, the World Bank. We have chosen to use per capita gross domestic product (GDP) expressed in purchasing power parity (PPP) terms in order to limit distortions caused by exchange rate fluctuations. When income data for specific country-years are missing, we impute the missing values using income data from the Penn World Tables (PWT). However, simply importing those data points would be problematic, as the two data sets differ in their calculations. Instead, we run a separate linear regression for each country for which there are missing data. World Bank income data that *do* exist for the country become the dependent variable, and PWT income data are used as the independent variable. The regressions then provide estimates for any missing World Bank country-years based on the PWT data. Country-years that are missing income data from both data sets are eliminated.

8. Comparing CE consumption to real income

Having calculated per capita food consumption in terms of cereal equivalents, we then regress CE consumption on per capita real income. Plots of the actual data reveal that food consumption measured in cereal equivalents rises rapidly with income at low income levels, but tapers off as incomes rise. We therefore chose a functional form that reflects this trajectory:

$$C_{CE} = \alpha - \beta e^{-kGDP}$$

where C_{CE} is consumption measured in cereal equivalents, α is the maximum consumption level which countries asymptotically approach at high incomes, and both β and k are parameters. In running the regression for total CE consumption for all available country-year data between 1975-2011 (4084 observations), we get the following results as indicated by the top curve. Further disaggregation by food type yields the divisions underneath.


Food Consumption as a Function of Real Income, by Food Category
Total Consumption
Residual
Bovine, Mutton, and Goat Meat
Milk
Pig Meat
Poultry and Eggs
Crops (Cereals, Vegetables, Fruits)
Tons of Cereal Equivalents per Capita per Year
Real GDPPPP (2005 US $)
0.00
0.50
1.00
1.50
2.00
2.50
0
5000
10000
15000
20000
25000
30000
35000
40000
45000
50000

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