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Estimating household and institutional food wastage and losses.

Measuring food deprivation and food excess in the total population

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Estimating household and institutional food wastage and losses in the context of measuring food deprivation and food excess in the total population (*)

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CONTENT

SUMMARY

The FAO's measure of food deprivation, the prevalence of undernourishment, is conceptually based on a comparison of dietary energy intake (DEI) with a normed minimum energy requirement which is compatible with a healthy life while performing light physical activity, taking into account the inequality in access to food. The inequality is expressed in terms of the biological variation and non-biological variation among individuals in the population.

Data sources for deriving dietary energy intake used in estimating the prevalence of undernourishment, the national food balance –NFB- and the household surveys - HHS, aim to measure food consumption as proxy of food intake. However, neither of them takes into account the amount of household or institutional food wastage and losses after food has been acquired by the population, that is, household (for private consumption) or institutional (for public consumption) food wastage and losses.

This paper describes a statistical procedure for estimating DEI based on dietary energy consumption (DEC) adjusted for household food wastage. It also proposes an estimating function of household and institutional food wastage and losses to better approximate food intake for the purpose of measuring food deprivation and food excess. The paper concludes that more empirical data is needed to improve the methodological development and the assessment world food wastage in the effort of measuring food deprivation and food excess; however it recommends, for the time being, using the proposed approach for estimating food wastage based on dietary energy consumption.

I. Introduction

The FAO's measure of food deprivation, also called the prevalence of undernourishment, is conceptually based on a comparison of dietary energy intake (DEI) with a normatively specified minimum dietary energy requirement (MDER) taking into account the inequality in access to food in terms of the biological variation due to sex-age and physical activity variations among individuals and the socioeconomic variation due to different levels of income and other income related factors within the population. The proportion of the population with dietary energy consumption below the MDER is taken as the prevalence of undernourishment (FAO 1996 – The 6th World Food Survey).

According to this approach DEI, expressed in terms of per person per day, follows a log-normal probability distribution with parameters μ and σ. These parameters are yearly estimated on the basis of data from national food balances (NFB) or less frequently from household surveys (HHS) collecting food consumption and expenditure data, in terms of food quantities, that are then converted into dietary energy, called dietary energy consumption (DEC) as proxy of DEI.

The MDER used in estimating the prevalence of undernourishment is a population based weighted average of MDER for different age and sex, which is compatible with a healthy life while performing light physical activity.

Both data sources on food consumption, NFB and HHS, aim to measure food consumption as proxy of the dietary energy intake using different data collection procedures. However, neither of them takes into account the amount of food wastage or losses after food has been acquired by the population. Thus the actual food intake may be lower than the food consumption measured by HHS or by NFB. Food wastage refers to all foods appropriate for human consumption that has not being consumed by the population. It includes plate waste, spoiled foods, unrecorded food given to pets (unrecorded feed), composted and put in garbage disposals or lost in preparation.

Evidently, food wastage may be a major source of bias of final DEI estimates (FAO Statistics Division, 1983). It is therefore important to account for wastage in calculating food intake, for the non-food use and food losses incurred between food acquisition and intake cannot be ignored; this occurs even when food supplies fall short of needs (Harrison, Rathje and Hughes, 1975; and Mercado-Villavieja, 1976).

The aim of this document is to describe a statistical procedure for adjusting DEC for food wastage so as to arrive at a closer approximation of DEI. The DEI, i.e. DEC after adjusting for food wastage and losses, would be used in the estimation of under-nourishment and over-nourishment.

The document is structured as follows. First, the background reports on a literature review related to household food wastage based on a preliminary report (FAO, 2004); second, a description of the statistical framework for estimating the distribution of dietary energy intake based on dietary energy consumption and food wastage; third, an illustration of parameter estimation applied to a limited dataset from Philippines; lastly, a proposal of a provisional function for adjusting the food consumption data in the context of estimating the prevalence of food deprivation and food excess.

II. Background

The need to consider food wastage for estimating food consumption was identified as early as 1939 (Chatfield, 1956). Since then, there have been many attempts to estimate household food wastage. However, due to its complexity, it has been very difficult to obtain acceptable estimates.

Most of the work has been done in developed countries, namely in the United Kingdom and in the United States of America. Other studies have been carried out in developing countries such as Philippines, Korea, Tunisia, Guatemala, Honduras, Costa Rica, Cuba, El Salvador, Panama, Peru and Paraguay (Chun *et al*, 1986; Chatfield, 1956; and, Mercado-Villavieja, 1976).

Some studies have measured household food wastage as a percentage of total consumed calories, others as a percentage of total weight of consumed food or as percentage of each of the consumed food-items. Furthermore, the estimated food wastage in terms dietary energy varied considerably, ranging from 0 to 29 percent, regardless the definition used; however, the majority of food wastage estimates fall within a range from 10 to 15 percent.

Some studies have estimated lower food loss in low-income households than in high-income households (Fung and Rathje, 1982; Chun, 1986; and, Jones, 2003). However, Wenlock *et al* (1980) did not find differences by household income levels, even after taking into account household size and geographical region. Dowler (1977) found similar results of no correlation between income and food wastage. Van De Reit (1985) concluded that household income is related to food wastage but in a non-linear manner. Moreover, it has been noted that high income households with adequate storage facilities e.g. refrigeration and enclosed cabinets, produced greater edible food wastage (Mercado-Villavieja, 1976).

Some studies found a tendency for large-size families to waste more food than small-size families (Dowler, 1977; Wenlock and Buss, 1977; and, Wenlock *et al*, 1980), while others argued that in large-size families or families with small children, food wastage is not a concern (Fung and Rathje, 1982).

Among household characteristics, the knowledge respondents on food safety and quality issues had the strongest negative correlation with overall quantity of food wastage (Harrison, Rathje and Hughes, 1975; Fung and Rathje, 1982).

The wide range of estimates and findings in the literature can be explained by the differences in the way food wastage is defined and measured, methodological differences, sample sizes, geographical location and household characteristics (Kantor, 1998).

Methodologies vary considerably, from weighing edible food waste to using 7-day diaries completed by household members and from calculating caloric content of food to physically sorting garbage. In some cases, estimates were derived indirectly from loss coefficients based upon existing research. Some of the studies used very small sample sizes while others were performed at a more aggregate level than households (regional or national).

In many studies domestic animals and garbage disposals were not accounted for in estimating household food wastage, thus yielding inaccurate estimates (Harrison, Rathje and Hughes, 1975; Wenlock and Buss, 1977; and, Jones, 2003). In some cases the wastage due to food used as feed to pets reached 30% of total food wastage in dietary energy terms (Wenlock *et al*, 1980; and, Mercado-Villavieja, 1976).

Studies in the United States show that food eaten outside of home is another important part of household consumption. During 1994-1996, meals eaten outside the household provided 32% of total energy consumption (USDA, 2003). Even though this percentage may be lower in developing countries, the data collected should account for meals eaten outside to give more accurate estimates of actual food consumption and hence of food wastage (FAO Statistics Division, 1983) and the institutional food wastage in restaurants, hospitals, schools, army barracks, religious residences, street vendors and other establishments needs to be accounted for.

An interesting finding emerging from the literature is that many researchers believe that the estimates obtained are too low, suggesting that better methods should be used (Adelson, Asp and Noble, 1961; Adelson *et al*, 1963; Dowler, 1977, Wenlock and Buss, 1977; Wenlock *et al*, 1980; Fung and Rathje, 1982; Rathje, 1984, Van De Reit, 1985; Kantor *et al*, 1997; and, Jones *et al*, 2003).

Because of the lack of standardization in estimating food wastage, it is difficult to identify the most accurate methodology. Moreover, most of the estimates that rely on exogenous food loss coefficients are derived from studies dating back to or before the 1970s. In the last three decades, technological progress contributed to fast changes in markets, distribution systems, household storage facilities etc., thus outdating the estimates (Kantor, 1998; and, Naska, 2001). Moreover, wastage was usually measured as a constant proportion of food consumed. However, there are strong indications that there is a non-linear dependency between the magnitude of wastage and income level. It is also well-known that the total amount of food consumed is highly associated with income level as described by Engelian functions. This leads to the conclusion that food wastage may be related to the total food consumption in a non-linear manner and that how to obtain reliable estimates of food wastage needs further development. In the next sections an attempt on these lines is presented.

III. Statistical framework for estimating the distribution of dietary energy intake based on dietary energy consumption and food wastage

FAO's approach for measuring food deprivation relies on the estimation of the theoretical probability distribution of DEI. The parameters of this distribution are specified by the average estimated from the NFB (or HHS) and the coefficient of variation due to non-biological factors estimated from HHS. Since the DEI estimate from NFB does not take into account household and institutional food wastage and losses, the estimate of DEI is upward biased. Some claim that, as the distribution of DEI is to be lognormal, the biases are likely to be concentrated in the long upper tail representing the richer and more affluent population groups. Hence estimated prevalence of undernourishment, being based on the short lower tail is not like to be far from the true value, at least for developing countries (Naiken, 2002). However, it is also admitted that this might not be the case for developed countries and countries in transition. Moreover, the yet-to-be estimated prevalence of overnourishment refers to the upper tail of the distribution, where the upward bias due to household food wastage is deemed to be much higher than in the lower tail of the distribution. In view of these elements there is need to adjust the DEC data to better estimate DEI.

A. Approach to adjusting DEC for food wastage

The principles emerging from the literature research relating to food wastage can be summarized as follows:

1. Household food wastage is related to household income level.
2. The relationship between household wastage and income may be of non-linear nature.
3. The non-linear relationship may vary among territorial (urban/rural) and/or functional (economic activity, household composition, etc) population groups.
4. The household food intake is related to household income level in a non-linear manner.

With respect to the consumption distribution, the two parameters of the lognormal distribution μ and σ are derived on the basis of the estimates of mean and coefficient of variation (CV). The NFB's estimate of DEC (expressed in kcal/person/day) is taken as the mean and the CV is derived from HHS data on DEC. Thus given these measures actually referring DEC, the parameters of the lognormal distribution are derived as follows:

$$\sigma^2 = \ln(CV_{DEC}{}^2 + 1)$$

$$\mu = \ln(\mu_{DEC}) - 0.5\sigma^2 ,$$

where CV_{DEC} is the coefficient of variation of DEC and μ_{DEC} is the mean of DEC.

Given the above considerations the approach chosen was to express wastage as a function of DEC and to use this function to adjust or modify the parameters of the log-normal distribution. This aspect is addressed below.

B. Alternative functions for estimating food wastage and their effects on the parameters of log-normal distribution

Let μ_a and σ_a be the parameters of the distribution of DEI (dietary energy intake) after adjustment for food wastage. The way in which these parameters differ from to the original ones will depend on the type of function used for estimating food wastage. The effect of alternative functions is discussed below.

1. Food wastage as a proportional share of DEC

First, let's suppose that wastage W is a constant proportion of DEC, e.g. $W = kDEC$. In this case the adjusted-for-wastage DEC will be equal to

$$DEI = DEC - W = DEC - kDEC = (1-k)DEC ,$$

where DEI is dietary energy intake. Since DEI is a linear transformation of DEC, the distribution will remain lognormal.

From the properties of mean and variance, we can write

$$\mu_{DEI} = E(DEI) = E[(1-k)DEC] = (1-k)E(DEC) = (1-k)\mu_{DEC}$$

and

$$\sigma_{DEI}{}^{2} = VAR(DEI) = VAR[(1-k)DEC] = (1-k)^{2}VAR(DEC) = (1-k)^{2}\sigma_{DEC}{}^{2}.$$

The first property can be applied directly to calculate μ_a. To calculate σ_a, the adjusted coefficient of variation needs to be estimated.

The unconditional coefficient of variation is a composite measure that is formulated as follows

$$CV_{DEC} = \sqrt{CV_{DEC/V}^{2} + CV_{DEC/R}^{2}},$$

where $CV_{DEC/V}$ is the coefficient of variation of DEC due to non-biological factors (income and related factors) and $CV_{DEC/R}$ is the coefficient of variation of DEC due to biological factors such as sex, age, weight and physical activity. The latter correspond to the distribution of energy requirement induced by mentioned biological factors and it is considered as a fixed component of CV_{DEC} and it has been estimated approximately to 0.20 (Naiken, 2002) based on the recommendations on human energy requirements of the 1981 FAO/WHO/UNU Expert Consultation. Therefore, the interest is on changes in $CV_{DEC/V}$ only. Since

$$CV_{DEC/V} = \frac{\sigma_{DEC/V}}{\mu_{DEC/V}}$$

the coefficient of variation due to income after adjusting for household food wastage is equal to:

$$CV_{DEI/V} = \frac{\sigma_{DEI/V}}{\mu_{DEI/V}} = \frac{(1-k)\sigma_{DEC/V}}{(1-k)\mu_{DEC/V}} = CV_{DEC/V}.$$

Thus, the overall coefficient of variation therefore remains unchanged.

In such case

$$\mu_a = \ln(\mu_{DEI}) - \sigma_a{}^{2}/2 = \ln[(1-k)\mu_{DEC}] - \sigma_a{}^{2}/2$$

and

$$\sigma_a{}^{2} = \sigma^{2}.$$

Therefore, if the wastage is expressed as a constant proportion of DEC, the adjusted distribution will have a lower scale parameter (μ) and the same shape parameter (σ) with respect to the original distribution.

2. Food wastage as a non-proportional share of DEC

Now, let's suppose that household food wastage is a linear function of DEC with an intercept. Then $W = a + bDEC$ and
$DEI = DEC - W = DEC - a - bDEC = -a + (1-b)DEC$.

The adjusted coefficient of variation due to income

$$CV_{DEI/V} = \frac{(1-b)\sigma_{DEC/V}}{-a + (1-b)\mu_{DEC/V}}$$

and the overall coefficient of variation

$$CV_{DEC} = \sqrt{CV_{DEC/V}^2 + CV_{DEC/R}^2} = \sqrt{(\frac{(1-b)\sigma_{DEC/V}}{-a + (1-b)\mu_{DEC/V}})^2 + CV_{DEC/R}^2}$$

Therefore $\mu_a = \ln(\mu_{DEI}) - 0.5\sigma_a{}^2 = \ln[-a + (1-b)\mu_{DEC}] - 0.5\sigma_a{}^2$

and $\sigma_a{}^2 = \ln(CV_{DEI}{}^2 + 1) = \ln([\frac{(1-b)\sigma_{DEC/V}}{-a + (1-b)\mu_{DEC/V}}]^2 + CV_{DEC/R}^2 + 1)$.

Again, the DEI is expressed as a linear function of DEC, thus the distribution remains lognormal. The new parameters are smaller than the original ones.

3. Food wastage as a non-linear function of DEC

As the literature review suggests, there might be two cases of non-linear dependence between household food wastage and dietary energy consumption. One is when food wastage rises at a higher rate than DEC and the second when it rises at a slower rate. These two cases could be represented by exponential and logarithmic relationships between W and DEC, respectively.

In such cases, the derivation of the parameters may become more complicated. However, the Taylor series expansion provides an approximation of mean and variance; the approximation depends on how close the function of the random variable lies to the first (or higher) order of the approximation over the range of the random variable (*ibid*); for the sake of simplicity, the estimations have been made using the first order (see **Annex**).

Based on the DEI estimates, that is, DEC adjusted-for-wastage, mean and variance and the function of the dietary energy intake, the new distribution can be derived.

IV. Estimating parameters of functions to measure household wastage

Datasets for estimating parameters for food wastage functions are very scarce. In this report the data from the Philippines 1978 First Nationwide Nutrition Survey (FNNS) is utilized for deriving function parameters for estimating food wastage in terms of dietary energy.

The household food wastage by income levels is estimated based on secondary data of food quantity consumption in households, expressed in dietary energy value, and the actual dietary energy intake by household members for different income levels. Food wastage is derived from food consumption minus food intake.

1. The Philippines 1978 FNNS dataset.

The data set used consists of two parts:
(a) average quantities of food items consumed per person per day, by income classes (National Science Development Board – Food and Nutrition Research Institute, 1981)
(b) average daily per person calorie intake corresponding to food groups, by income classes (FAO Statistics Division, 1993)[1].

[1] The data on average daily per capita calorie intake were prepared by the Food and Research Institute of the Philippines, on request of FAO for the FAO Sixth World Survey. Therefore, these numbers were

Both the average quantities of food items consumed per person per day and the average daily per person calorie intake are derived from the Philippines 1978 FNNS data. The survey covered eleven regions of the country, excluding western and central Mindanao.

Food expressed in nutritive values refers to the amount of food intake, i.e. the net intake of food in edible portion form, after deducting household wastage of prepared food in form of plate wastes, food discards and leftovers. Food eaten outside home was also accounted for in estimating both the average food consumption and food intake. The quantities of food items consumed refer to food as purchased, i.e. including inedible and edible food portions (FAO Statistics Division, 1993).

Information on food intake in the households was collected for one whole day by the weighting method and 24-hours recall method. The items weighted refer to the following:

- raw (purchased) food to be cooked for each meal;
- food served and eaten raw;
- cooked (processed) food served directly on the dining table;
- non-perishable items such as coffee, sugar, cooking oil and the like; and
- food wastage in every meal and leftovers.

Data on meals and snacks eaten outside, as well as on characteristics of household members and annual income were also collected (*ibid*).

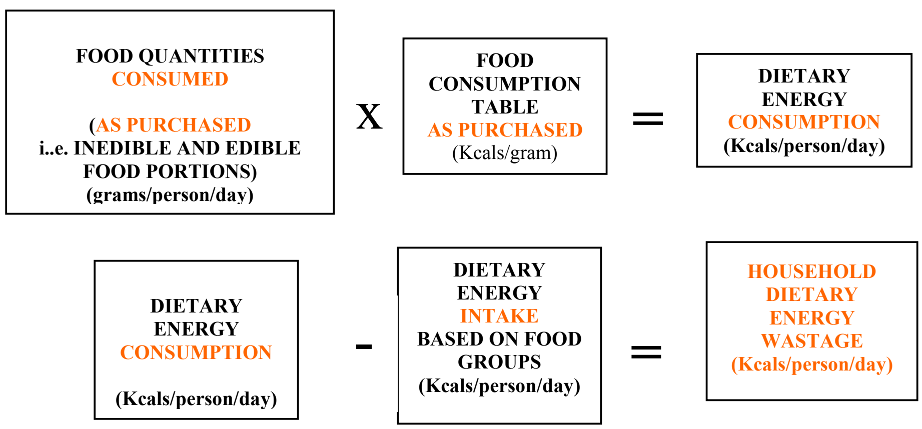
Data on average quantities of food items consumed and on average calorie intake, both expressed on per person per day basis, were reported for different income groups. These data were re-grouped to cover the same intervals of income classes. The reported income classes were aggregated into three broader groups on the basis of annual per person income: 1) lower than 1000 Pesos; 2) higher than or equal to 1000;

not reported in the National Science Development Board – Food and Nutrition Research Institute (1981).

and 3) higher than or equal to 1500 Pesos. These re-grouped income classes did not have any particular reason other than matching the two datasets by income classes. Weighted estimates were calculated by average household size. These weights were not reported for food consumption data but for food intake data.

2. Methodological framework

The following diagram describes the methodological framework:



As the diagram shows, the food consumption was converted into the corresponding dietary energy consumption using Food Composition Table (FCT) for the Philippines published by the NSCB-ESSO (National Statistical Coordination Board – Economic and Social Statistics Office) (1988a and 1988b). The food quantities consumed refer to as purchased i.e. inedible and edible portions of food, then corresponding dietary energy values in the FCT in kilocalories per 100 grams 'as purchased' of food were used (NSCB-ESSO, 1988b). The data on calorie intake are given only for food groups and not for single food items. Therefore the data on food consumed were converted into calories by food groups and not by food items; hence, also the food consumed had to be estimated by food groups rather than by food items. The dietary energy wastage is calculated as the difference between average DEC and average DEI corresponding to food groups, by income classes.

3. Household food wastage estimates

Table 1 shows results on preliminary household food wastage estimates in terms dietary energy, in absolute value (kilo-calories per person per day) and as share of DEC (%), based on food group by income levels. The results for total household wastage are in line with most findings reported in the literature. However there are estimations that are implausible, in particular, meat-and-offals, fats and oils, eggs and pulses-and-nuts; these estimates of wastage are negative. In the case of fats-and-oils and eggs, the negative household wastage is very close to zero and could be associated with rounding errors – the starting data being rounded to the closest integer, therefore, the 'true' value is assumed to be zero. In the case of large negative of food wastage such as meat-and-offals and pulses-and-nuts food groups, stocks changes were ruled out as a source of the negative wastage. The reasons for these negative values may be related to acquisition of certain food items that are fully edible that food composition tables considers with a non-edible portion, e.g. meat without bone, nuts without shells.

Table 1. Household wastage by income level: Preliminary estimates

Food group	Income classes (Pesos per person per day)							
	0-999	1000-1499	1500 & over	All classes	0-999	1000-1499	1500 & over	All classes
	Absolute Wastage (Kcals per person per day)				*Wastage as share of DEC (%)*			
Cereals and Products	14	-11	-3	8	*1*	*-1*	*0*	*1*
Roots and Tubers	26	20	1	20	*40*	*32*	*6*	*34*
Sugar and Syrups	10	38	79	28	*14*	*29*	*41*	*28*
Fats and Oils	-3	-3	43	8	*-4*	*-2*	*20*	*7*
Fish and Sea Food	10	8	-5	7	*15*	*10*	*-7*	*11*
Meat and Offals	-15	-42	-63	-22	*-49*	*-59*	*-44*	*-41*
Eggs	0	-1	-2	-1	*-4*	*-3*	*-5*	*-6*
Milk and Products	28	77	114	51	*55*	*61*	*63*	*62*
Pulses and Nuts	-3	-3	-2	-4	*-19*	*-13*	*-8*	*-19*
Vegetables	20	21	19	19	*35*	*35*	*32*	*34*
Fruits	10	36	18	15	*21*	*41*	*21*	*25*
Stimulants	24	42	31	28	*69*	*69*	*63*	*68*
Total	**120**	**183**	**230**	**157**	***7***	***9***	***10***	***8***

Table 1 above shows food wastage results based on food groups in all income classes varies from an assumed zero (meat-and-offals, eggs and pulses-and-nuts) to 68 % (stimulants). Overall the higher the income, the higher the wastage, however, for some food groups (e.g. roots and tubers or fruits), the highest income class wastes less than the middle income class, which reflects different food wastage patterns by income classes.

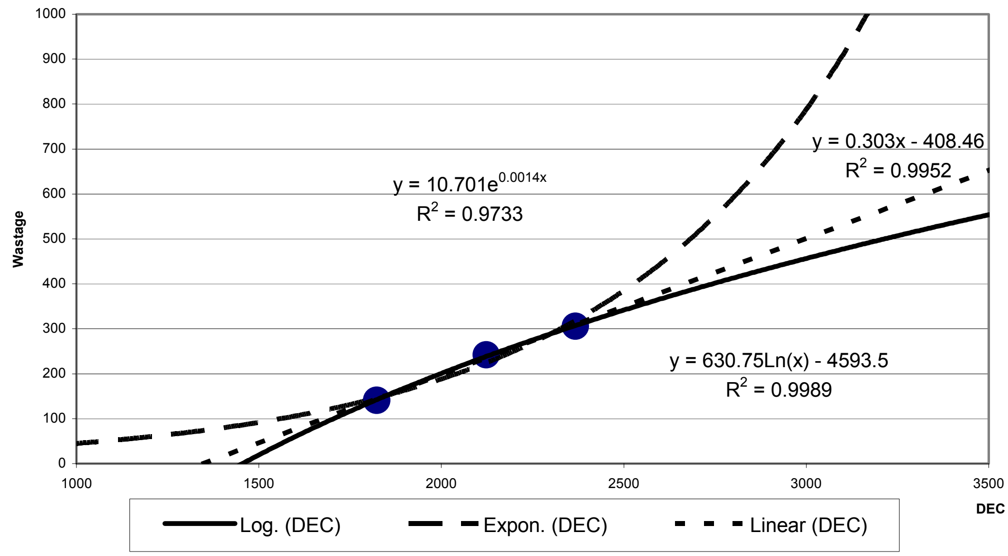
Table 2 shows food wastage final results based on the mentioned assumptions described in previous paragraphs. The overall food wastage is equal to 9% of total DEC. Households of the lowest income class waste 8% of total food, while the middle class wastes 11% and the highest income class 13%. There is a positive association between size of food wastage and income. The higher the income is, the higher the amount of DEC. Hence household food wastage is positively associated with total amount of DEC.

Table 2. Household wastage by income levels: Final estimates

Food group	Income classes (Pesos per person per day)							
	0-999	1000-1499	1500 & over	All classes	0-999	1000-1499	1500 & over	All classes
	Absolute Wastage (Kcals per person per day)				*Wastage as share of DEC (%)*			
Cereals and Products	14	0	0	8	*1*	*0*	*0*	*1*
Roots and Tubers	26	20	1	20	*40*	*32*	*6*	*34*
Sugar and Syrups	10	38	79	28	*14*	*29*	*41*	*28*
Fats and Oils	0	0	43	8	*0*	*0*	*20*	*7*
Fish and Sea Food	10	8	0	7	*15*	*10*	*0*	*11*
Meat and Offals	0	0	0	0	*0*	*0*	*0*	*0*
Eggs	0	0	0	0	*0*	*0*	*0*	*0*
Milk and Products	28	77	114	51	*55*	*61*	*63*	*62*
Pulses and Nuts	0	0	0	0	*0*	*0*	*0*	*0*
Vegetables	20	21	19	19	*35*	*35*	*32*	*34*
Fruits	10	36	18	15	*21*	*41*	*21*	*25*
Stimulants	24	42	31	28	*69*	*69*	*63*	*68*
Total Food Wastage	**141**	**242**	**305**	**184**	***8***	***11***	***13***	***9***
Total DEC Values	1823	2124	2368	1961				

Graph 1 depicts equations fitted for linear (with intercept only) and non-linear relationships between DEC and wastage using three points of the Philippines data.

Graph 1. Fitting household food wastage functions



The relationship between DEC and household food wastage was explored by fitting regression curves using the three data points as follows:

1) linear, $W = 0.303DEC - 408.46$

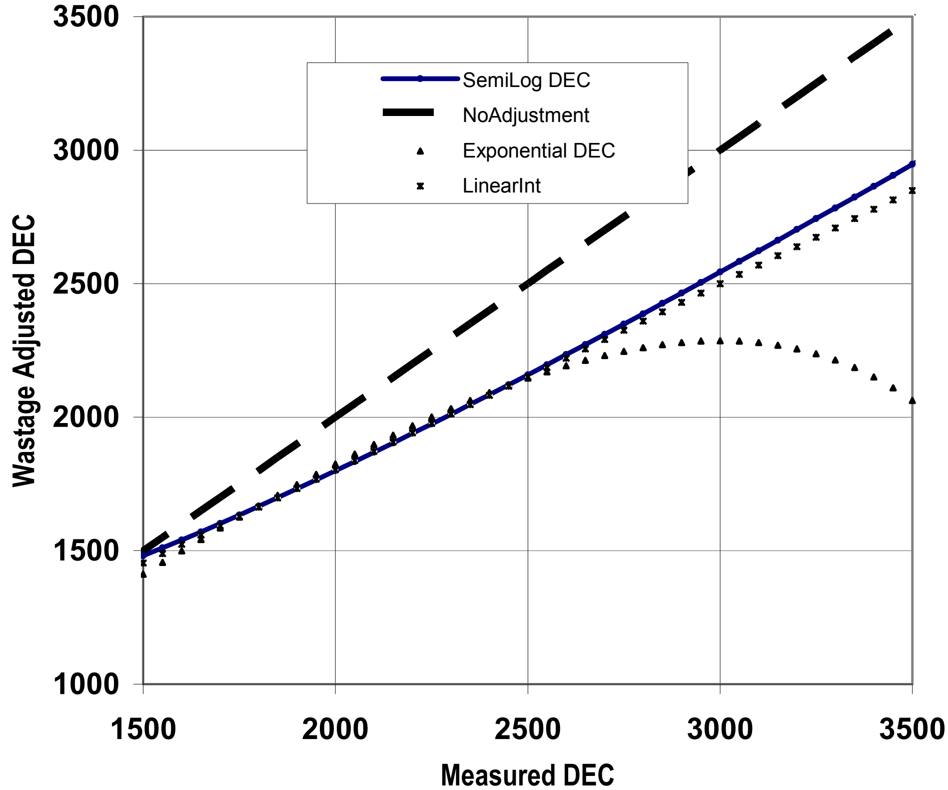
2) non-linear:

a) exponential, $W = 10.701\exp(0.0014DEC)$

b) semi-log, $W = 630.75\ln(DEC) - 4593.5$.

All functions yield high similar goodness of fit due to the few data points available. Graph 2 describes DEC and DEI, i.e. DEC adjusted for linear, logarithmic and exponential household food wastage functions. First the linear function adjusts with the same relative share for food wastage to all DEC levels. This adjustment is against the assumed principle. The logarithmic function adjusts more to higher DEC and less to low DEC levels. This function complies with the assumed principle; however the difference between this function and the linear function is small.

Graph 2. DEC and DEI by wastage functions



The exponential function adjusts more to higher DEC and less to low DEC levels. The level of adjustment to low DEC levels is similar to the other two functions; however the adjustment in high DEC levels is significantly higher. The estimated functions are not reliable enough, but provide an idea of the sort of functions that may be useful.

In the next section all functions obtained using Philippines study results are applied to a hypothetical example.

3. Improving DEI estimates in light of estimated household food wastage in the Philippines.

As described previously the estimated distribution of DEI will change according to the type of household wastage function applied. This section applies the Philippine results to the theoretical framework to a hypothetical example.

Following Naiken's (2002) numerical example to estimate the distribution of DEI for a particular country:

$\hat{\mu}_{DEC} = \hat{\mu}_{DEC/V} = 2414 \ \ kcals/person/day$ and

The estimated

$\hat{C}V_{DEC/V} = \frac{508}{2414} = 0.2104$, given $\hat{\sigma}_{DEC/V} = 508$ so that

$\hat{C}V_{DEC} = \sqrt{0.2104^2 + 0.2^2} = 0.29$ and

$\hat{\sigma}_{DEC} = 700.06$.

In this case, the original parameters of the lognormal distribution are equal to

$\hat{\sigma}^2 = \ln(0.29^2 + 1) = 0.08075$

$\hat{\mu} = \ln(2414) - 0.08075/2 = 7.7487$.

The next step is to calculate the adjusted parameters. This will be illustrated below.

a) Wastage expressed as a function of DEC.

(i) Wastage expressed as a proportion of DEC .

Suppose that wastage is a constant proportion k of DEC, where k is equal to the average wastage (%) in all income classes. Therefore:

$\hat{W} = 0.09D\hat{E}C$ and $D\hat{E}I = 0.91D\hat{E}C$. The $\hat{\mu}_{DEI} = 0.91\hat{\mu}_{DEC} = 2196.74$ and

$\hat{C}V_{DEI} = \hat{C}V_{DEC} = 0.29$ as shown above. Therefore, $\sigma_{DEI} = 0.29 * 2196.74 = 637.0546$ and the adjusted parameters $\sigma_a{}^2 = \sigma^2 = 0.08075$ and

$\mu_a = \ln[(0.91)\mu_{DEC}] - 0.08075/2 = 7.65435$.

The distribution remains lognormal. Graph 3 below shows the comparison of original and adjusted probability density functions. The adjusted probability density function is shifted to the left and slightly less spread out.

(ii) Wastage expressed as a non-proportional share of DEC

In this case wastage is dependent on DEC in the following way $\hat{W} = -0.408.46 + 0.303D\hat{E}C$. Thus $D\hat{E}I = 408.46 + 0.697D\hat{E}C$,

$\hat{\mu}_{DEI} = 408.46 + 0.697\hat{\mu}_{DEC} = 408.46 + 0.697 * 2414 = 2091.018$,

$\hat{C}V_{DEI/V} = \dfrac{0.697 * 508}{408.46 + 0.697 * 2414} = 0.16933$,

$\hat{C}V_{DEI} = \sqrt{0.16933^2 + 0.2^2} = 0.26205$ and

$\hat{\sigma}_{DEI} = 0.26205 * 2091.018 = 547.96$.

The adjusted parameters $\hat{\sigma}_a{}^2 = \ln(0.26205^2 + 1) = 0.066415$ and

$\hat{\mu}_a = \ln([408.46 + 0.697 * 2414]) - 0.066415/2 = 7.6122$.

Once again, the distribution remains lognormal. Graph 3 below shows the graphical comparison of original and adjusted probability density functions in the case of linear dependence between wastage and DEC. The adjusted probability density function is shifted to the left and less dispersed. The adjusted probability function is less dispersed when wastage is a linear function of DEC than when it is a proportion of DEC.

b) Wastage a non-linear function of DEC

i. Logarithmic

The Taylor series approximation can be used to derive the mean and the variance of the adjusted DEC (see Annex). Therefore, if $g(DEC) = DEI$ as defined above, $\mu_{DEI} = E(D\hat{E}I) = E[g(D\hat{E}C)] \approx g(\hat{\mu}_{DEC}) = D\hat{E}I = D\hat{E}C - \hat{W}$

$$= 2414 - (630.75\ln(2414) - 4593.5) = 2095$$

and

$$\hat{\sigma}^2_{DEI|V} = VAR(D\hat{E}I \mid V) = VAR[g(D\hat{E}C \mid V)] \approx [g'(\mu_{DEC|V})]^2 (CV_{DEC|V}\mu_{DEC|V})^2$$
$$= (1 - 630.75\frac{1}{2414})^2 (508)^2 = 140824.22$$
$$\hat{C}V_{DEI/V} = \frac{0.54569 * 508}{2095} = 0.1323$$
$$\hat{C}V_{DEI} = \sqrt{0.1323^2 + 0.2^2} = 0.2398 \text{ and}$$
$$\hat{\sigma}_{DEI} = 0.2398 * 2095 = 502.4 .$$

The adjusted coefficient of variation $\hat{C}V_{DEI} = 0.24$. Having the estimate of the mean and the variance of the adjusted DEC, the distribution of DEI can be derived. Graph 3 below shows the distribution of DEI after adjusting for food wastage.

ii. Exponential

The adjusted mean of dietary energy consumption and the adjusted coefficient of variation are estimated as previously. The wastage function is $\hat{W} = 10.701EXP(0.0014D\hat{E}C)$ and the adjusted dietary energy consumption is equal to $D\hat{E}C - 10.701EXP(0.0014D\hat{E}C)$. The Taylor series approximation yields the mean and the variance of the adjusted DEC, if $g(DEC) = DEI$ as defined above,

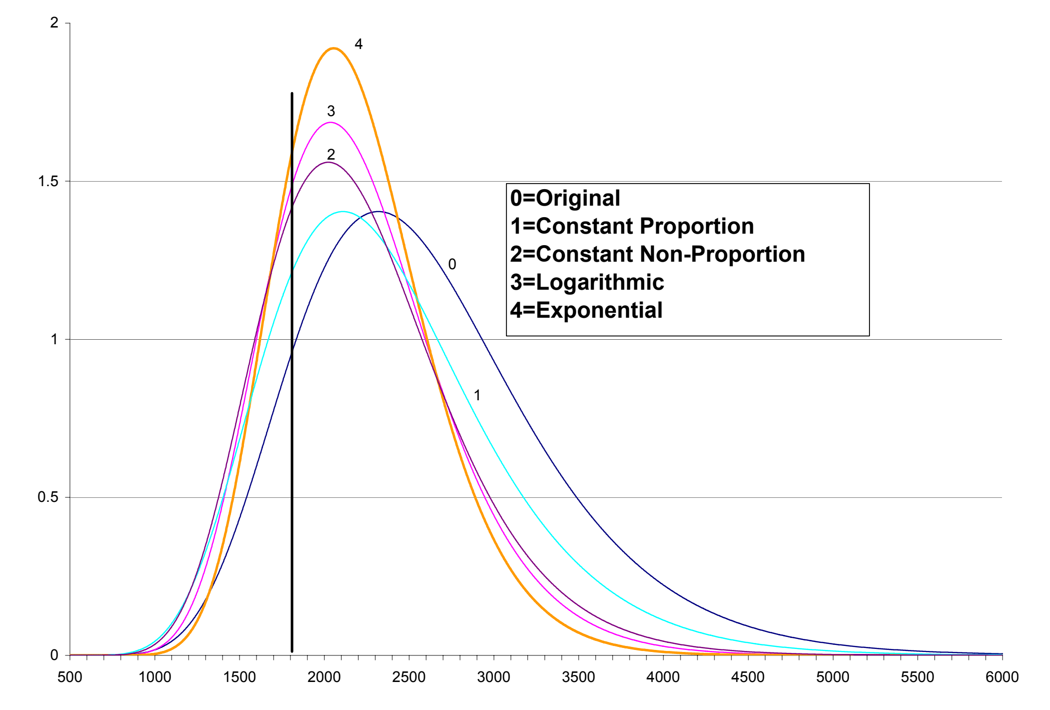
$$\mu_{DEI} = E(D\hat{E}I) = E[g(D\hat{E}C)] \approx g(\hat{\mu}_{DEC}) = D\hat{E}I = D\hat{E}C - \hat{W}$$
$$= 2414 - 10.701EXP(0.0014 * 2414) = 2100$$

and

$$\hat{\sigma}^2_{DEI|V} = VAR(D\hat{E}I \mid V) = VAR[g(D\hat{E}C \mid V)] \approx [g'(\mu_{DEC|V})]^2 (CV_{DEC|V}\mu_{DEC|V})^2$$
$$= (1 - 10.701 * 0.0014 * \exp(0.0014 * 2414))^2 (508)^2 = 153778.564 .$$
$$\hat{C}V_{DEI/V} = \frac{0.31378 * 508}{2100} = 0.0759 ,\ \hat{C}V_{DEI} = \sqrt{0.0759^2 + 0.2^2} = 0.2139 \text{ and}$$
$$\hat{\sigma}_{DEI} = 0.2139 * 2100 = 449.23 .$$

The adjusted coefficient of variation $\hat{C}V_{DEI} = 0.21$. Graph 3 below shows the distribution of DEI after adjusting for food wastage.

Graph 3: Wastage adjusted and original density functions of DEC



5. Summary of parameter estimations.

The main findings are summarized in Table 3 below and depicted in Graph 3 above. In all cases DEI distribution is shifted to the left (lower mean) and the variance is reduced (as measured by the CV_{DEI}), except when W is estimated as a proportion of DEC. The prevalence of undernourishment p(U) are higher than the original one, due mainly to a lower DEI as compared to DEC rather than to a decreased inequality as measured by CV_{DEI}.

The changes in the magnitude of the basic parameters of the distribution of DEC adjusted for food wastage, μ_{DEI} and σ_{DEI}, show that adjustment for wastage is important. The largest effect occurs when using the exponential function.

Table 3. Summary.

	non-adjusted estimates	DEI estimates			
		W as a proportion of DEC	W as non-proportional of DEC	W as a non-linear (semi-log) function	W as a non-linear (exponential) function
μ_{DEI}	2414	2197	2091	2095	2100
CV_{DEI} %	29	29	26	24	21
σ_{DEI}	700	637	548	502	449
distribution	lognormal	lognormal	lognormal	~lognormal	~lognormal
%p(U) at MER=1800	18	29	29	24	21

6. Limitations

The main limitation is related to data availability for estimating proper food wastage functions. The Philippines dataset is subject to many biases; first, the data refers to one-day period (24 hours recall method). The two aggregated datasets used, even though part of the same survey, were prepared for different purposes and food consumption was reported in the survey report, while food intake was prepared in a special report requested by FAO, few years later. The data were grouped into two incompatible income classifications, rendering the comparison between datasets less than desirable. Only three common income groups were considered for wastage estimation and the estimating function may be biased. Finally, the Philippines is a country where the diet is on average relatively low in calories (Mercado-Villavieja, 1976). Therefore, the food wastage estimating functions may differ considerably from countries where the diet is higher in dietary energy. The parameters of the regression functions may vary from country to country, so that the coefficients estimated for Philippines may be different to other countries.

Further studies are needed to validate the wastage calculations presented in this study and the function to be used to improve undernourishment estimates at the regional and country levels. In view of the above, the next section proposes a non-linear function that has been calibrated so that distributional characteristics are met.

V. Provisional function for adjusting the food consumption data in the context of estimating the prevalence of food deprivation and food excess

The problem of household wastage has so far been downplayed as FAO has been interested in the estimation of the prevalence of undernourishment only and in this context the focus is on the lower tail of the consumption distribution where wastages are likely to be minimal or negligible. However there is now an interest in estimating the prevalence of over-nourishment also where the focus is on the upper tail of the consumption distribution i.e. the region where wastages are concentrated. Therefore the problem can no longer be ignored.

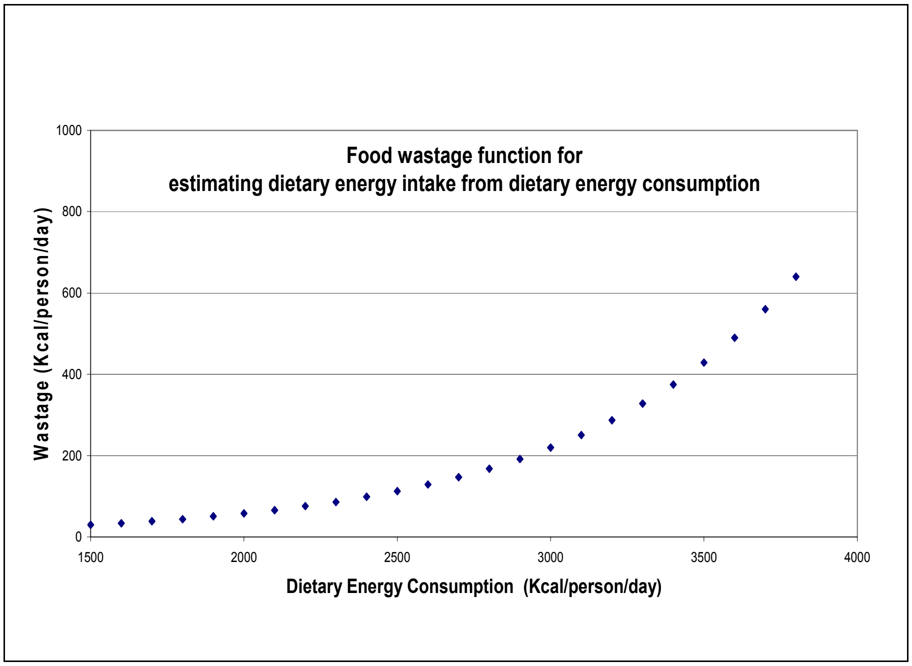
In view of the above a wastage function based on pragmatic considerations is considered in order to adjust the food consumption data for household wastage. In this context, as there is a strong indication that the proportion of wastage is likely to increase with food consumption, a function of the following form is suggested

$$W = a\, b^{cX}$$

where W represents wastage and X dietary energy consumption.

This family of functions, which implies higher proportion of wastage as food consumption increases in a non-linear manner, is compatible with empirical evidence from the Philippines data set. However, for the purpose of practical application the parameters a, b and c have to be calibrated so as to ensure that the function does not lead to unacceptable results, e.g. a) wastage at consumption levels below that corresponding to the need for survival and body maintenance b) inequality in the distribution of intake that is below certain minimum level (i.e. the inequality due to the variation in energy requirement), and c) wastage estimates outside the range of 0 to 30 percent.

Simulations carried out suggest that the following parameter values would ensure acceptable wastage levels: a = 4, b = 2.1 and c = 0.0018 . The graph below portrays the function based on these parameter values.



The above function leads to percentage wastage estimates ranging from 2 to 17 for dietary energy consumption levels ranging from around 1500 to 3800 kcal/person/day. In other words, the dietary energy intake estimates fall within the range from around 1470 to 3160 kcal/person/day. For the particular case of Philippines DEI is reduced by 100 kcals, 4.1% of wastage with respect to DEC, with adjusted CV of 15% and prevalence of undernourishment of 18%; the distribution is shrunk and moved to a higher DEI value in mean.

This proposed function would be applied to all countries in the world until a new function is developed with reliable empirical data.

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Annex: The Taylor series expansion

Suppose that a random variable X has E[X] = μ_x and VAR(X) = σ_x^2 and g(x) is a twice continuously differentiable, i.e. the first derivative of g(x), g'(x) and the second derivative g''(x) exists and is continuous, then $g(x) \approx g(\mu_x) + g'(\mu_x)(x - \mu_x)$ (Kendall and Stuart, 1977).

This suggests that $E[g(x)] \approx E[g(\mu_x) + g'(\mu_x)(x - \mu_x)] = g(\mu_x)$ and $VAR(g(x)) \approx VAR(g(\mu_x) + g'(\mu_x)(x - \mu_x)) = (g'(\mu_x))^2 \sigma_x^2$.

Therefore, in the case of the adjusted parameters, this becomes

$$g(DEC) \approx g(\mu_{DEC}) + g'(\mu_{DEC})(DEC - \mu_{DEC}),$$

$$\mu_{DEI} = E[g(DEC)] \approx E[g(\mu_{DEC}) + g'(\mu_{DEC})(DEC - \mu_{DEC})] = g(\mu_{DEC})$$

and

$$\sigma_{DEI}{}^2 = VAR[g(DEC)] \approx VAR[g(\mu_{DEC}) + g'(\mu_{DEC})(DEC - \mu_{DEC})] = [g'(\mu_{DEC})]^2 \sigma_{DEC}^2,$$

where $\sigma_{DEC}^2 = (CV_{DEC}\mu_{DEC})^2$.

These approximations can be improved by adding more terms in the Taylor series approximations. If we add one more term we obtain

$$E[g(x)] \approx E[g(\mu_x) + g'(\mu_x)(x - \mu_x) + \frac{1}{2} g''(\mu_x)(X - \mu_x)^2] = g(\mu_x) + \frac{1}{2} g''(\mu_x)\sigma_x{}^2$$

and

$$VAR(g(x)) \approx VAR(g(\mu_x) + g'(\mu_x)(x - \mu_x) + \frac{1}{2} g''(\mu_x)(x - \mu_x)^2)$$

$$= (g'(\mu_x))^2 \sigma_x{}^2 + \frac{1}{4}(g''(\mu_x))^2 (VAR(X^2) - 4\mu_x{}^2 \sigma_x{}^2.$$