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WP 46 September 1988

World Institute for Development Economics Research of the United Nations University

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* The research underlying this paper has been conducted while the author was on leave from the IIES, working at WIDER. The paper has benefited from comments from participants at the IIES and WIDER seminars. Special gratitude goes to Henrik Horn, Siddiq Osmani and Amartya Sen, and also to Anna Thompson who assisted in the word processing.

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Abstract

The objective of this paper is to develop a model that integrates the biologically determined human need for food energy and the economic activity (most) people must engage in to be able to eat. The optimal work effort and the optimal body size of individuals in nutritionally constrained populations are derived. The model suggests that such individuals are economically better off keeping their work activity and body size down. The nutritional requirement of the individual is derived endogenously in the model and contrasted to the exogenously determined nutrition norms used by the FAO/WHO and other international organizations in order to assess the food situation in the poor countries.

In the household version of the model, the optimal intra-family distribution of work activity and of food consumption, as well as the optimal male/female body weight ratio, are derived. The model suggests that in the economic optimum, the woman works more intensively then the man in relation to the food she consumes and that her optimal body weight (for height) is higher than the man's.

The paper is part of a larger study that has as its main aims to assess the nutrition situation in Sub-Saharan Africa and to explain the reasons for the undernutrition that exists. According to the international organizations, the world's food problems of today are concentrated in Sub-Saharan Africa. The FAO claims that the food 'available' in the region in the mid 1980s is only 80 percent of what is required even if distributed equally, which it is not. The World Bank has estimated that almost half the population in the region is undernourished and one-quarter severely so.

In the larger study, the main corollaries following the analysis in this theoretical paper are tested on data from a large set of countries in Sub-Saharan Africa. The theoretical finding that the type of 'exogenous' nutrition norms used by the FAO/WHO and the World Bank induces a substantial upward bias in the estimated prevalence of undernutrition, is vindicated by the tests. The empirical analysis also corroborates the theoretical argument why women in this region have a higher body weight (for height) than men and, by implication, works harder relative to what they eat.

CONTENTS

1. INTRODUCTION

The link between nutrition and economic productivity has been analysed extensively by economists. The notion that poverty ***causes*** *undernutrition* goes back at least to Adam Smith and poverty is still the main explanatory variable in most contemporary attempts to explain poor nutrition (FAO, 1985; IBRD, 1986; Srinivasan, 1981). It has also been suggested that the causation goes in the opposite direction; that poor nutrition is the ***reason*** for low productivity and poverty. This idea dates back to Leibenstein (1957) and has subsequently been given a more rigorous formulation by several authors (cf. below).

The objective of this article is to develop a model of the interactions between biologically determined human needs for energy (calories) and the economic activity that the individual must pursue in order to be entitled to food. Some features of the model are similar to those of the earlier 'efficiency wage' model(s). The main similarities and dissimilarities are briefly summarized in section two; the more subtle distinctions are highlighted as we proceed. The basic properties of the model are presented in section three. In section four, the main results are reported. The optimal work effort and body weight for the nutritionally constrained individual are derived endogenously and some simple comparative static experiments are conducted. In section five, the model is aggregated to the household level and the optimal intra-family allocation of work effort, calorie intake and male/female body weights are deduced. In section six, the model is used to define 'calorie requirements' which are endogenously determined. The paper closes with a short summary and a few suggestions for further analysis.

2. THE RELATED LITERATURE

The backbone in the theoretical literature aimed at explaining low productivity by poor nutrition is the so-called efficiency-wage-requirement function. It is derived on the presumption that the amount of 'efficient' work that can be carried out by laborers is a function of the wage they receive, which determines their consumption, inclusive that of food. The model developed below is based on the same general notion of a relationship between food, or rather the energy contained in food, and work activity. This model is different in several specific respects, however.

First, in the previous literature, the level of aggregation is the 'farm', the 'rural sector', or the 'economy'. Here the focus is on the individual and, subsequently, the household. Second while nutrition is one of the factors used to explain the efficiency-wage-requirement function, the nutritional aspects have not been modelled very explicitly.[1] In the present model, the notions of nutritional balance, intra-individual adaptation to poor nutrition and the optimal body weight are derived endogenously. Third, previous models have one good only, i.e. 'consumption', which is assumed to be equal to the wage and the labor output. In the present model, there are two goods: 'calories', which is assumed to have the property of an **intermediate** good, and 'non-calories', a (composite) ***consumption*** good. The individual's objective is to arrive at an optimal trade-off between the consumption of non-calories and leisure given his budget and nutritional-requirement constraints. Fourth, 'undernutrition' has not been considered at all in

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1 This pertains in particular to the papers by Mirrlees (1975), Stiglitz (1976) Bliss and Stern (1978a) and the contributions contained in Akerlof and Yellen (1986). A somewhat more explicit modelling of some of the biological-nutritional aspects are found in Bliss and Stern (1978b) and Dasgupta and Ray (1986, 1987a-b).

the efficiency wage models (Mirrlees, 1975 and Stiglitz, 1976), or been superimposed on the basis of exogenously determined 'recommended' requirements of the FAO type (Bliss and Stern, 1978b), or set at an arbitrary consumption level (Dasgupta and Ray, 1986, 1987a, 1987b). In the present model, nutritional requirements for different objectives are derived endogenously.

The phenomena that previous models aim at explaining also differ from those here. The main concern in Mirrlees (1975), Stiglitz (1976) and Dasgupta and Ray (1986, 1987a, 1987b) is to explain involuntary unemployment and income distribution under different market structures; in Bliss and Stern (1978a-b) the focus is on the positive theory of wage determination. In this model, wages are exogenously determined by aggregate demand and supply in the economy in which the individual works.[2] We do not consider unemployment; rather the focus is on differences in productivity across people. The main concern here is how the (poor) individual's economic and biological behaviors are affected by the fact that food (calories) is needed as an *input* in his earnings of income, as compared to the standard model where food is just one of many consumption goods. The optimal work effort and the optimal body weight and, thus, the calorie requirement of individuals and households in nutritionally constrained populations, are derived endogenously in the model.

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[2] In his assessment of the efficiency wage models, Bardhan (1979) finds the theoretical and empirical support for nutrition-, or efficiency-based, monopsonistic wage setting in India to be weak; rather, he finds more support for the hypothesis that wages are determined by aggregate demand and supply in the different labor markets.

3. THE MODEL

The model to be developed below builds on three functions. The first is biologically determined and traces out the relationship between the energy intake and the energy expenditure (physical activity) of an individual (he in the following). The second is essentially a production function that describes how this physical (work) activity is translated into income and non-calorie consumption. The third is a utility function with non-calorie consumption and leisure as the elements. The reference individual is assumed to work in an economy with perfect competition in all markets, signifying that all prices and wages he faces are given. The model is static and concerned with the medium, rather than the short (days, weeks) or long term (years). The individual has a fixed initial bundle of productive assets. The only form of savings and credit in the model is the individual's (household's) possibility to accumulate and decummulate energy stores in the own body.

3.1. The Calorie Expenditure Function

The human body needs the energy (and other nutrients) contained in food to maintain different processes and activities. The most basic is the sustainment of ***internal*** body functions (respiration, blood circulation, etc.), the ***basal metabolism rate*** (BMR). (During early periods in life, energy is also needed for internal work in the form of growth of body size and women need extra energy during pregnancy and for lactation; these needs are not considered here.) In addition, the body requires energy in order to be able to pursue ***external*** physical activities, such as work. Energy is also required for maintaining ***health***. When the energy expenditure for all these activities match the energy intake, and there is no change in body composition, the person is in ***nutritional balance***, as the term is.

For the moment we shall distract from health and focus solely on the energy needs for internal (BMR) and external physical activity. This part of the model, based on a layman's interpretation of the theory of human biology, is depicted in Figure 1. The ***habitual*** (daily average over the medium term) calorie intake, C, of a 'reference' adult individual of given stature, sex and age is measured along the vertical axis. The level of ***external*** energy expenditure, or the external physical activity (A), that this individual exerts, is measured along the horizontal axis.

The calorie requirement for ***internal*** activity is assumed to be a positive function of the individual's weight (although not necessarily linear).[3] For a particular weight, the calories required for internal body work (BMR) is thus given, at, say, C_b in Figure 1.[4]

In the theoretical nutrition literature, it is difficult to find an exact specification of how the calorie intake is related to energy expenditure for ***external*** physical activity. Here we assume that the calorie intake needed for external activity for the individual who is ***in nutritional balance***, is a non-linear function that has one increasing

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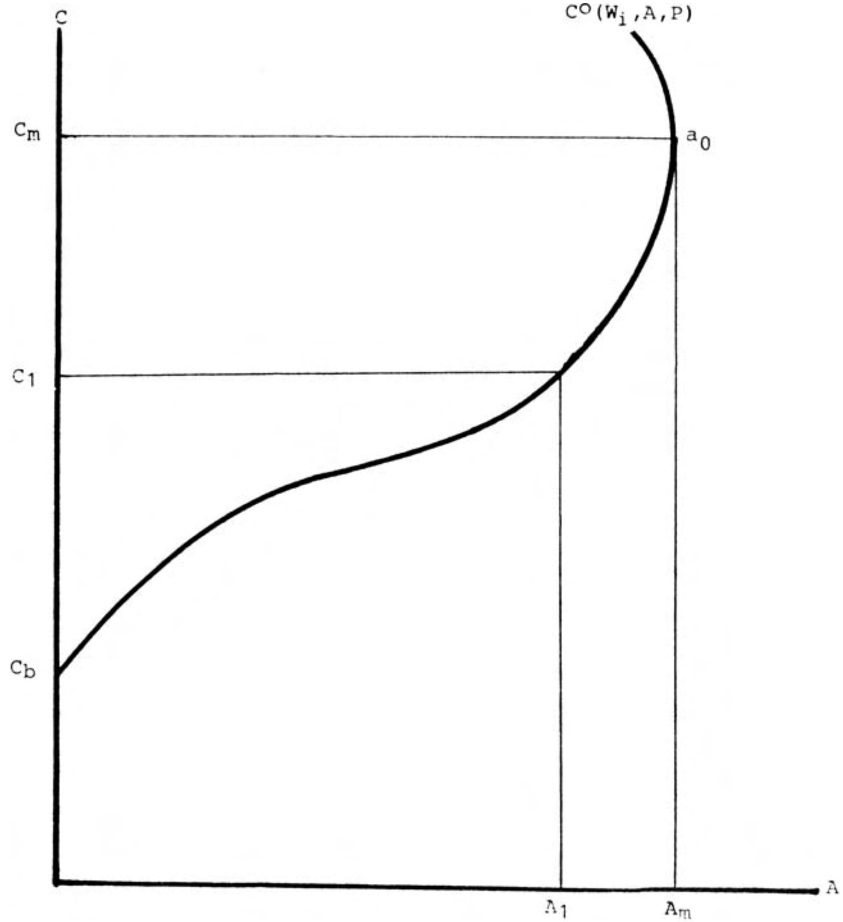
3 At this theoretical stage it is not necessary to be very specific about how and by what standard external 'activity' should be measured. It can be though of as the amount of physical work that the individual can pursue. In more operational terms, it can be approximated with the maximum volume of oxygen uptake (VO_2 max), which is 'an indicator of the maximum amount of energy that can be liberated by skeletal muscles and hence the maximum amount of work that can be done' (Osmani, p. 58).

4 The reference individual is assumed to be an adult, but the special requirements growth in stature and concomitant gain in weight for a child can be represented in the model. Growth in stature implies that requirements for internal activity increase; the 'intercept' determined by the BMR shifts upwards along the vertical axis as the child grows. *The extra calories needed by women during pregnancy can be* represented in rather the same way in the figure.

Figure 1



and one decreasing portion. More specifically, we assume that this relationship has the bell-formed shape depicted by the $C^O(W_i,A,P)$ curve in Figure 1. W_i refers to a particular body weight (i) of the reference individual and A is the level of external activity and P is a vector of 'personal' characteristics, such as age, height, sex, etc., which are assumed to be given. This particular form of the intake-expenditure function is reasonably consistent with the findings of the empirical work on nutrition and aerobic capacity (the literature is surveyed in Spurr, 1983).

The nutritionally ***unconstrained*** individual is assumed to have a (daily average) maximum physical activity level that he can maintain (A_m). To attain this maximum activity level, he needs a certain calorie intake, C_m, in Figure 1, in order to stay in nutritional balance (constant weight). A calorie intake **above** C_m will not permit increased activity. Per unit of time, the body can only transform a given amount of energy contained in food into forms that can be used for external activity. Extra calories, above C_m, will reduce the external activity level attainable; overeating will cause indigestion and drowsiness and some of the 'excess' calories will dissipate through increased body wastes and thermogenesis (body heat generation). The $C^O(W_i,A,P)$ curve will thus bend leftwards above C_m. Most of the 'excess' calories will accumulate as fat, however, and the body weight of the individual will increase (cf. below).

An external activity level **below** the physical maximum, say A_1, will require a lower calorie intake, C_1, in the case shown in Figure 1. All points on the $C^O(W_i,A,P)$ curve represent stationary equilibria in the sense that the individual is in nutritional balance (neither gaining nor loosing weight). That is, nutritional balance can be obtained at an infinite number of combinations of calorie intake and expenditure.

There are, however, not only an infinite number of combinations of intake and external activity that leave the individual in nutritional balance. The individual can be in nutritional balance at various body weights. Each weight corresponds to a different BMR and a different intake-expenditure function. There is thus a whole 'school' of $C^{o}(W,A,P)$ curves, one for each weight. At a low weight, requirement for BMR is reduced, but so is the maximum activity the body can exert. At a high weight (obesity), the BMR is increased, while the maximum ***external*** activity potential is **reduced** for the simple reason that the obese individual has to move his own fat around. However, the maximum activity in absolute terms that the individual can produce is dependent on his weight (for given height, genetic heritage and other factors in the P vector that we assume cannot be changed). Let us thus define the $C^{o}(W,A,P)$ curve that is consonant with the highest possible, nutritionally unconstrained, external activity for the individual; this is the $C^{o}(W_m,A,P)$ curve in Figure 2.[5] W_m is thus the body weight that permits the individual to exert his maximum physical capacity.

In Figure 2, several intake-expenditure functions have been drawn; each one refers to a particular body weight of the reference individual. The ***envelope*** for all these curves traces out the combinations of habitual calorie intake, on the one hand, and body weight and energy

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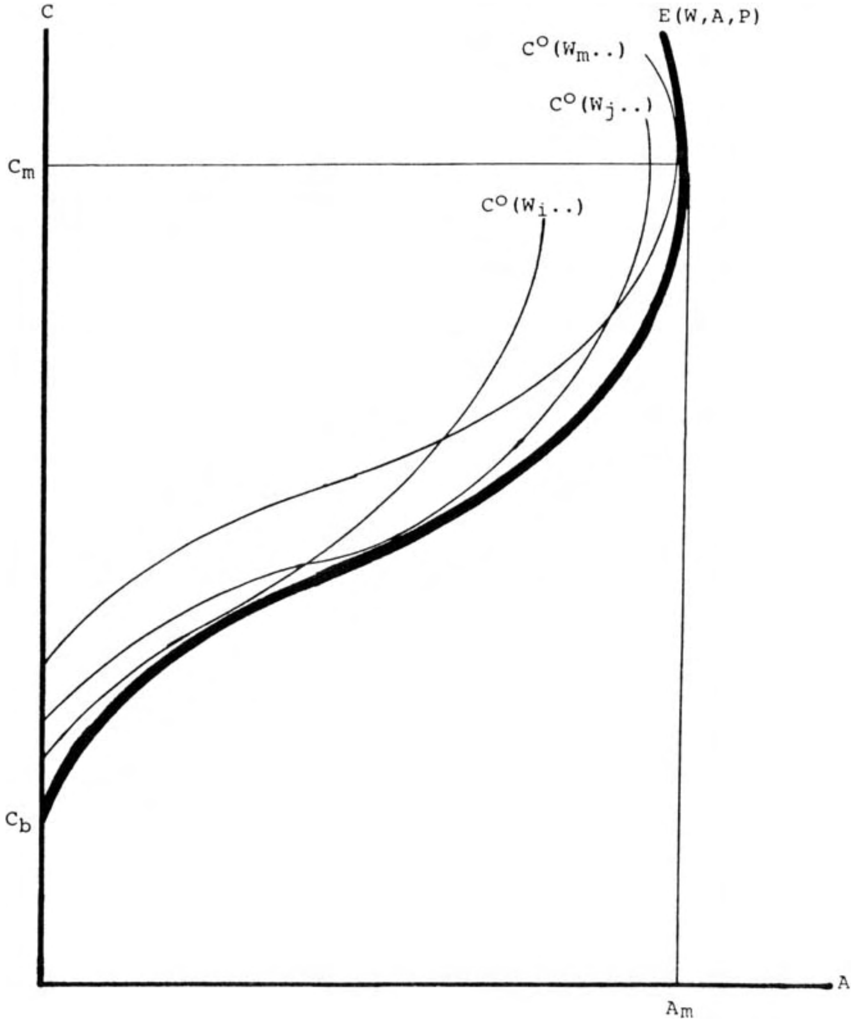
[5] In some of the recent nutrition literature it has been postulated that the body has a built-in mechanism which sees to that the energy consumed is more efficiently used during prolonged periods of nutritional stress, i.e. there is ***intra-individual adaptation*** to a low calorie intake. This notion is readily represented in the model. It simply means that the calorie expenditure function has a smaller intercept and lies at a lower level than if such a mechanism does not exist.

Figure 2



expenditure (external activity level), on the other, at which the individual can be in nutritional balance (the heavy curve). This is what we will call the individual's ***calorie expenditure-weight function*** and denote **E(W,A,P)**.[6] (In the following we will ignore the portion of the expenditure function that bends 'backwards', as we are not concerned with problems of obesity.) As one moves from the left to the right along this curve, the different stationary equilibria represent successively higher external activity levels ***and*** body weights. The intercept of the E(•) function is left unexplained for the moment; later on it will be derived endogenously.

3.2. The Calorie Revenue Function

As illustrated by Figure 2, from a purely biological point of view, the individual can be in nutritional balance at a very large number of combinations of calorie intakes, body weights and external activity levels. In a world where food entitlements are based mainly on the individual's (or household's) own work, which requires energy, the number of combinations is restricted.

In Figure 3, three functions are depicted: one is the ***calorie expenditure-weight function*** derived earlier, the **E(A,W,P)** envelope curve. The **R(A,K,Q)** curve is what will be called the ***calorie revenue function***. It is essentially an 'efficiency labor' production function

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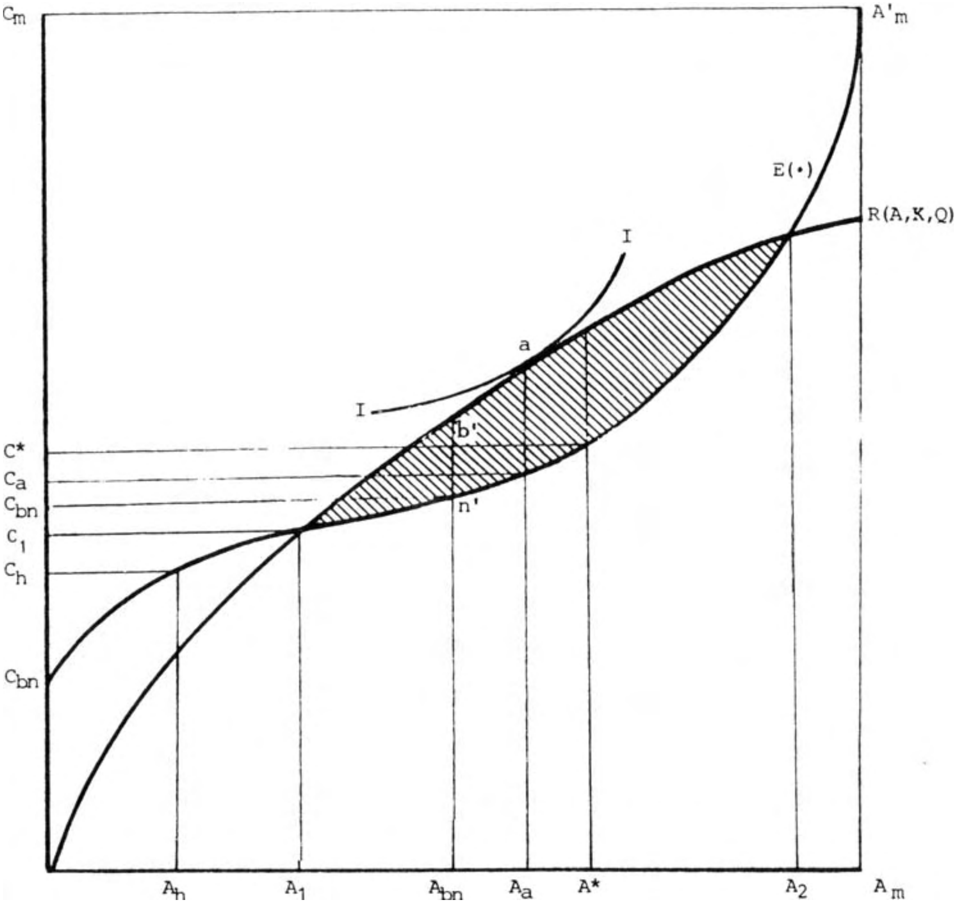
[6] It should be noted that neither the $C^O(\bullet)$ nor the E(•) curve is the same as the efficiency-wage-requirement function in previous models (although they may look similar). The EWR curve traces out the economic ***contribution of laborers*** working at a farm (Stiglitz, 1976) or a factory (Mirrless, 1975), as a (positive) function of the wage they receive. The $C^O(\bullet)$ and the E(•) functions derived here depict the ***biological relationship*** between energy intakes and expenditures (external physical activity, however used) at different body weights for an individual. ***Economics*** have yet to be introduced in the model (in sub-section 3.2).

Figure 3



that traces out the economic return to the individual's physical work effort. His income is thus assumed to be a monotonic and positive function of the activity (number of hours per day and work intensity) he puts into the work, A, for fixed values of his capital-stock vector, K (including land), and the price his output commands in the market, or the 'wage' his labor is rewarded with (the price vector Q).

The return to the labor effort is measured (along the vertical axis) in how many calories the work output can 'buy'. One can think of a subsistence farmer with own labor and land as the only inputs, which makes market prices immaterial. This case would be consonant with the concave production function shown in Figure 3, assuming that there are *decreasing marginal returns to labor effort for given amounts of capital* and land. Alternatively one can think of someone producing a good or service that earns a certain return in the market that is exchanged for calories (food). In this case it would be more appropriate to depict the revenue function as an upward sloping straight line. The exact shape of the function is not essential for any of the results or conclusions to be derived, however.[7] Since the body is assumed to have an upper limit

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[7] The technical property of this function may look similar to the **production function** in the particular efficiency wage model developed by Stiglitz (1976, Figure 4). His production function is that of the farm at which the laborers are employed, however, not that of the individual, as here. Also not that we have assumed wages to be given, i.e. to be determined by aggregate demand and supply in the economy in which the individual is working, not by a monopsonistic or egalitarian employer. A notable difference is also that Stiglitz is not concerned with the individual, his calorie needs and, thus, body weight and undernutrition. As he points out, however, all his results hinge on the assumption that his ***efficiency wage requirement function*** has a convex segment which he refrains from explaining (ibid, p. 187). Such a convexity is conveniently represented by an intercept corresponding to the calorie needs for BMR, the assumption used here and in Bliss and Stern (1978b).

to which it can transform food energy into physical activity,[8] this also limits the amount of physical work that the individual can undertake (at A_m). As external activity levels beyond A_m are not feasible, Figure 3 has been draw as a 'closed' box.

3.3. The Utility Function and the Integrated Model

In the case shown in Figure 3, the revenue function cuts the expenditure function twice (which is one of several possibilities; cf. below). At A_1, the individual's work will pay him exactly the equivalent of the calories he needs for BMR and the work activity itself (C_1). At A_2, the two curves intersect again, and a higher activity level (and body weight) means that the calorie expenditure exceeds the calorie revenue. The hatched area in Figure 3 thus represents the ***feasible set of consumption of non-calories*** that the individual is faced with. (Recall that calories are assumed to be an intermediate good that does not enter the utility function.)[9] What particular point in this set he will choose depends on whether his utility function includes a positive

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[8] This assumption is perhaps not altogether realistic in a long term perspective. A person can normally increase his physical capacity through exercise and training the way athletes do. This can be represented in the model as 'technological change' in the expenditure function; i.e. that shifts it to the right and increases A_m. In the following we will not consider this long-term possibility.

[9] Food can be treated as a good with several characteristics that enter the individual's utility functions separately, such as taste, texture and social stigma, which are 'consumption' characteristics, and energy, which we have assumed not to provide any direct utility, only indirectly in the production of income (leisure and consumption of non calories). The non-calorie properties of food are assumed to be part of the other, composite, good. Here we thus assume that the different 'characteristics' of food can be obtained as separate units. This is perhaps not a realistic assumption for localities where the variety in the food available is small. In most places, it seems to be a reasonable approximation, however. As an example, in southern India, a large number of rice varieties, the main staples, is for sale in most markets, commanding different prices per calorie. By choosing different kinds of rice, the consumer then has the possibility to obtain energy and, say, taste in the proportion he finds optimal given his budget constraint.

valuation of leisure. If so, his preferences can be represented by the convex indifference curve II in Figure 3.

3.4. Health Considerations.

Let us now turn the attention to the third 'objective' towards which nutritional requirement is usually related: health. Before this issue is analysed in terms of the model, however, a distinction is warranted. Nutritional inadequacy can make the individual less healthy and functionally impaired in different ways. The immunocompetence and some cognitive capabilities can be irrecoverably damaged by ***permanent*** nutritional stress in the formative years of childhood. It may also be that ***current*** *undernutrition leads to impaired health (more frequent,* severe and prolonged illness) and higher risk of death, ***given*** the immunocompetence that was built up earlier in life. In this paper, we shall only consider the relationship between current nutrition and health. The dietary 'history' of the individual is simply assumed to be an element in the vector of personal characteristics, **P**, in the expenditure-weight function.

So far we have only laid economic constraints on the ***minimum*** external activity that the individual can pursue and the ***minimum*** body weight he can live with. Taking health into consideration has implications for the interpretation of the model and means that an additional constraint is imposed on both external activity and body weight; ***it may be binding or not***. Health enters the model in three different ways.

First, a certain ***internal*** activity over and above the BMR is required during non-sleeping hours to allow for the increased muscle tone and the thermic effect of food digestion. Up to now we have interpreted the intercept of the expenditure function as the energy requirement for BMR. Since the individual cannot be asleep for 24 hours per day, the extra energy needed for increased internal body activity during non-sleeping hours has to be added to the intercept. Second, the physical activity needed for the maintenance of cardiovascular and muscular fitness lays a restriction on the ***minimum external*** activity the individual can pursue (say A_h in Figure 3). Third, the ***body weight*** (for height) can only be reduced to a certain level without endangering long-term health. (What has been estimated to be the 'critical' values, is discussed in Svedberg, 1989.)

4. RESULTS; THE INDIVIDUAL

In this section, the optimal work effort and body weight of the nutritionally constrained individual will be derived endogenously in the model. Simple comparative static experiments will be conducted and the possibility of below-optimum-body weight equilibria, 'poverty traps' and famine situations will be analysed subsequently.

4.1. The Optimal Work Effort

In the case where leisure does ***not*** enter the utility function, the optimal work effort is at A^* in Figure 3. At this activity, the vertical distance between the revenue and expenditure functions (the consumption of non-calories) is at a maximum, implying that the slope of the expenditure function (the marginal calorie expenditure) is equal to the slope of the revenue function (the marginal calorie revenue). On the other hand, if leisure and non-calorie consumption are substitutes (represented by the indifference curve II), he will choose activity level (A_a), corresponding to the point a, where the revenue function touches the highest attainable indifference curve.[10]

The work effort A_a thus represents the stationary equilibrium where the individual attains the highest possible combination of non-calorie consumption and leisure, and where he is in nutritional balance at the body weight that is optimal, given his two 'budget' constraints: income and the biologically determined needs for energy. However, this body weight must be **above** the lowest weight that is consistent with health in the long run. If not, the individual has to put on more weight so as to eliminate health risks, thereby reducing his non-calorie consumption. There may thus be a trade-off between consumption, on the one hand, and body weight and health, on the other.

The basic conclusion, however, is that it does not pay the low-productive individual to exert his maximum work capability. In fact, his optimal work activity may be much below what the nutritionally unconstrained individual would choose. Here we thus have a theoretical rationale for keeping work intensity down (possibly to the level that an uninformed beholder would consider laziness) even for individuals who have no preference for leisure in the conventional sense.

4.2. The Optimal Body Weight

Each point on the calorie expenditure-weight function represents a different stationary equilibrium body weight and the higher up on the function, the higher the weight. The economically optimal stationary equilibrium in Figure 3 implies a body weight that is below what the

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[10] In order to make sense in the context of the model, leisure has to be defined as a state that does not involve any ***external*** physical activity, e.g. resting. Leisure in the 'Western' meaning, i.e. non-working engagements that may involve heavy physical activity, such as sports, are not considered here.

nutritionally unconstrained individual would choose. That is, a low body weight will be economically more conducive than the 'normal' body weights observed in the rich countries. The notion that 'smaller is better' in nutritionally constrained populations has been suggested earlier in an informal way (e.g. Seckler, 1984). That individuals of working age in poor countries often are thinner than in the rich countries does thus not necessary imply that they are starved. A low body weight may be part of an adjustment that is economically motivated; the crucial question is whether the adjustment has proceeded below the weight that is consonant with health (this possibility is tested in the Sub-Saharan Africa context in Svedberg, 1989). Combining the results obtained in the two preceding sections, show a case for the nutritionally constrained individual to be 'small and lazy'.

4.3. Comparative Statics

It is notable that the expenditure-weight function is assumed to contain no variable that can change exogenously. Two of the variables in this function, A and W, are endogenous and the third, the vector of personal characteristics, P, is assumed to be given once and for all. All the exogenous variables are contained in the revenue function, i.e. the factor endowment, the technology and the price vectors. This means that the expenditure-weight function cannot shift; changes in the exogenous variables can only induce movements (second-order effects) along this function. A change in an exogenous variable will only induce a shift (a first-order effect) in the revenue function.

An increase in the price of the good (or service) supplied by the individual depicted in Figure 3, for instance, will shift the revenue function multiplicatively upwards. The optimizing individual's (with no preferences for leisure) response would be to increase his work activity and his body weight. That is, the new **maximum** consumption of non-calories would correspond to a point to the right of the initial location on the expenditure-weight function. A price decline would trigger a response in the opposite direction: a lowering of both work activity and body weight. In fact, the lower the productivity of the individual (cet. par.), the lower the optimal work effort and body weight.

The assumption that all the exogenous variables enter the revenue function implies that the causality in this model goes from low productivity (poverty) to a low calorie intake (and a low body weight), rather than the other way around. The empirical finding that 'farm productivity raises with improved nutrition' (Strauss, 1986) can thus not be reconciled with the model developed here. The idea that poor nutrition **causes** low productivity rather than vice versa, must be based on a presumption that poor individuals behave sub-optimally given the constraints they face. That is, the argument must be that, should they eat more and, by implication, consume less non-calories, their productivity and, thus, their income and total consumption would increase. Until a formal model which provides a theoretical rationale for the initial sub-optimal situation has been presented, the notion that the causation goes from poor nutrition to poverty must be treated cautiously.

4.4. Weight Transition and Sub-Optimal Body Weight Equilibrium

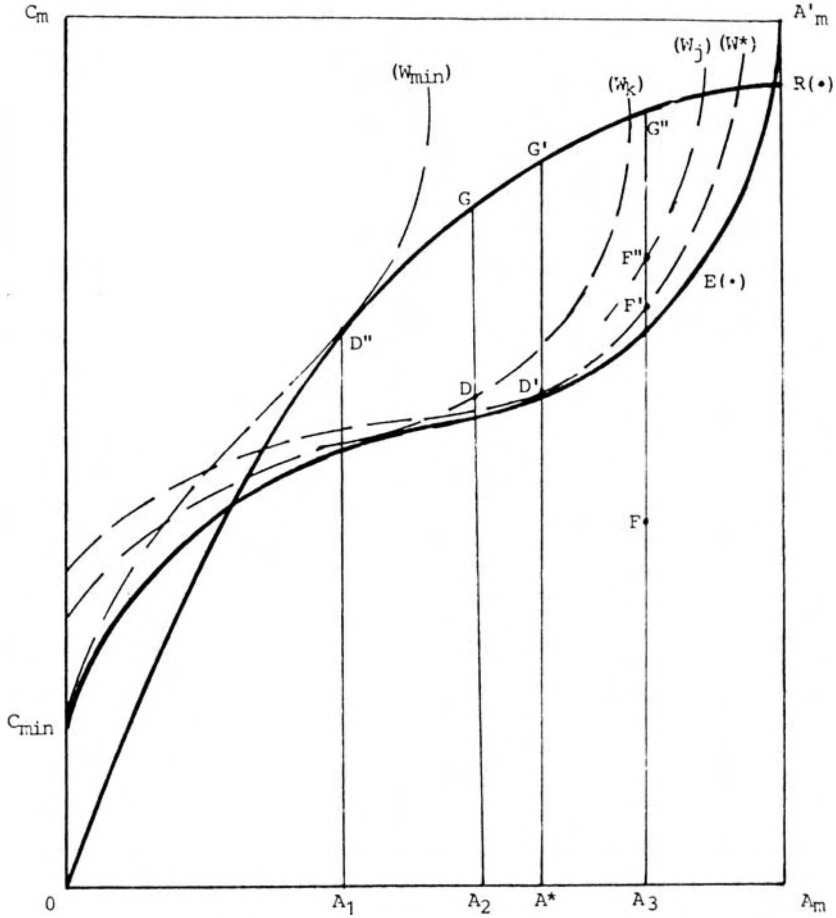
The transition from one body weight to another along the expenditure-weight function has so far been assumed to take place automatically and momentarily. Moreover, only situations where the individual is in nutritional balance have been considered. In this section, body weight transition and the possibility of ***stationary*** equilibria at ***suboptimal*** body weights will be analysed.

Over the short term, the individual can expend energy over and above his current intake by drawing on his body reserves. In terms of the model, a calorie expenditure to the right of the $E(\cdot)$ curve in Figure 4, say at F, is possible for some time. At this point, however, the individual is no longer in nutritional balance; his weight will decline.

Assume that the individual was in nutritional balance at the optimal weight corresponding to point D' (Figure 4) in the previous period, but that his appetite for non calorie consumption is suddenly whetted. In the current period he increases his work activity and reduces his calorie intake to the point F. In this period he will thus consume FG'' of non-calories as compared to D'G' in the previous period. Since his calorie expenditure now exceeds his current intake, his body weight will decline and he will enter the the subsequent period with body weight W_j instead of W^*. If he continues to have the intake/expenditure combination represented by F, the negative balance in the second period will be larger than in the first period, FF'' instead of FF', and his body weight will decrease further. With the intake/expenditure maintained at F, the depletion of body reserves will grow exponentially over time. Since the initial body reserves are limited, this cannot go on forever; the point F is not sustainable.

In order to get back to the optimal stationary equilibrium at weight W^*, the individual has to start accumulating body reserves instead of running them down. Assume that he has reached the state where his weight has dropped to W_k. At this body weight, he can no longer

Figure 4



maintain an intake/expenditure combination like F for the simple reason that this expenditure exceeds his physical maximum at body weight W_k. The individual is forced to reduce his external activity level. Assume further that he decides to put his house in order, i.e. to go back to the body weight and external activity level (at D') that is consonant with the maximum economic consumption of non-calories in the long-term. At his present weight, W_k, he can earn a maximum surplus of DG while being in nutritional balance. He can choose to stay at this weight, but it is a sub-optimal stationary equilibrium. In order to get back to the optimal body weight, W*, he has to start saving out of his surplus DG, i.e. to increase his calorie intake above D, while keeping his expenditure there.

The time and effort it will take to reach D' depends on (i) the size of the difference between his present weight and the optimal one, (ii) the size of his 'surplus' and (iii) the fraction of this he 'invests' in himself. In case his present body weight is far below the optimal, the attainable surplus is small and he attaches a positive discount rate on future non-calorie consumption, it may take a very long time to reach D'. In fact, it may never be achieved considering the limited life time of the individual.

4.5. The Poverty Trap.

The extreme outcome is when the body weight has declined to what is labelled W_{min} in Figure 4. That is, if the individual who started to decummulate his body reserves does not reverse the process, he will eventually reach a point like D''. At this point he will be able to survive, but not more. With the body weight W_{min} he can exert just enough external activity to earn the income required to buy the calories needed for BMR and the work activity itself. At this point there is no possibility to earn a surplus and, thus, to build up body strength and reserves. The individual would be in what one may call a **poverty trap**. He is cornered, he can survive, but he cannot get out (without outside credit or aid). Moreover, the slightest downward shift in his revenue function will be fatal; he would no longer be able to get command of the current calorie intake needed to survive (cf. section 4.5. below).

The body weight W_{min} is at the same time what determines the intercept of the expenditure-weight function, E(•). It is notable that the lowest body weight that is consonant with survival is not determined by biological factors only, but also by economic earnings. That is, with higher earnings (a revenue function above R(•) in Figure 4), the individual could live with a lower body weight than W_{min}. A higher revenue function would 'touch' an intake/expenditure function to the left of W_{min} (not inserted in the figure), which would also have a smaller intercept than C_{min}.

The lesson to be learnt is that it can be dangerous for the poor individual not to maintain a body weight with considerable reserves. A decummulation of body stores of energy entails the risk of ending up in a situation where there is no possibility to earn a surplus and get back to a body weight that permits earnings over and above what is needed for survival in a world where food entitlements are dependent on own work effort. The danger is especially pronounced since it is much more costly to build up reserves than to run them down. That is, the conversion in the body of energy contained in food to body energy stores entails a substantial loss while the decummulation is practically costless (cf. Bliss and Stern, 1978b, p. 370, footnote 6). The problem of significant changes in body weight is especially acute in poor economies where there is marked seasonality in the main economic activities, such as in non-mechanized agriculture in the semi-arid parts of the third world.

4.6. The Famine Case

In the situation depicted in Figure 5, the revenue function lies below the expenditure function over the entire range. In this case, the individual cannot support himself through work; he has a basal calorie requirement (C_b), but however hard he works, he will starve. One can think of this case representing an individual whose revenue function has shifted downwards in the wake of an exogenous 'shock'. The shock can either be that the price of the output he produces has declined, or that his real wage has been reduced (the Q in the revenue function), or that his productive assets (the K) have been destroyed by natural calamity, such as drought. Whatever the reason, the return to his work effort is simply too low to buy or produce enough calories to avoid starvation despite no ***unemployment*** or voluntary constraint on work activity.[11] This is so whatever body weight and work activity he chooses.

Since this individual cannot meet his current calorie needs, he cannot build up body reserves, or accumulate productive assets (increase

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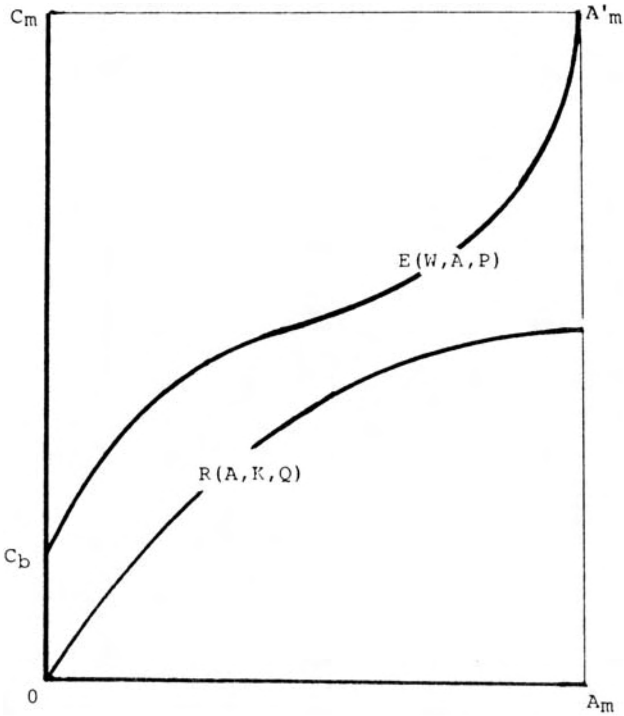
[11] In the related literature on 'efficiency wages', the main aim is to explain how (involuntary) unemployment can arise in markets with no stickiness in wages. The reasoning is that it is more profitable for the employer to hire a smaller number of workers and pay them the 'efficiency wage' than to hire a larger number and paying them less (cf. Mirrlees, 1975 and Stiglitz, 1976 and Dasgupta and Ray, 1986, 1987a-b). In none of these models, is there an explicit analysis of the relation between unemployment, lack of income and undernutrition and starvation. The 'unemployed' are assumed to survive on minor economic activities outside the model. That representation of 'unemployment' is not satisfactory in the present author's opinion. The representation here, i.e., people are not either employed or unemployed, but may be engaged in such low-rewarding activities that they starve seems to be a more general and realistic description of reality, at least in SSA, where landless labor is not a very common phenomenon.

Figure 5



K), which would raise the return to his work effort. Only through transfers from outside, or higher prices for his output, or a higher wage, can his revenue function be shifted upwards so as to cut the expenditure function. In the absence of such interventions, he would be in a fatal '***undernutrition trap***', he would loose weight successively and, eventually, perish.[12] When a large number of people within a confined geographical area and time span are in this situation, there would be what we usually refer to as a famine.[13]

5. RESULTS; THE HOUSEHOLD

The analysis conducted so far has been at the level of individuals. The typical production and consumption unit in the poor countries is larger, viz. the household or the family, nuclear or extended. In this section, we shall show how the model can be aggregated to the household level. We shall start by enlarging the model to represent a household comprising two adults, husband and wife. Subsequently, the optimal allocation of work effort and calorie intake within the family and the optimal male/female body weight ratio will be derived endogenously.

5.1. From Individuals to Households

The husband and the wife are assumed to be engaged in one and the same economic activity, say the family farm. Their labor skills are

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[12] The notion of an 'undernutrition' trap has been used by other authors with other meanings and explanations; see for instance Alamgir, 1978 and Dasgupta and Ray, 1987b.

[13] One can also think of other cases, e.g. where the revenue and expenditure functions intersect several times, or where the latter has an intercept high up on the vertical axis, representing the case of a 'super-rich' person, who only has to lift a finger (or the phone) to earn enough calories for his BMR.

further assumed to be perfect substitutes, i.e. they possess no individual-specific skills. They are assumed to differ in one respect only: they are of different sizes and, thus, have different BMR and **maximum** capacity for external (work) activity.

The man's and the woman's (biological) expenditure-weight functions are denoted $E_{♂}(\cdot)$ and $E_{♀}(\cdot)$ in Figure 6. The upper limit to the household's capacity of external (work) activity is given by the sum of the man's and the wife's maximum (i.e. $A_{mh} = A_{m♂} + A_{m♀}$). The sum of the calories required for the respective individual's maximum external activity is given by C_{mh}. Their joint expenditure function, the household ***minimum*** expenditure function, is $E_h(\cdot)$.[14] The household calorie revenue function is $R_h(\cdot)$. Given the assumption that the 'efficiency' labor of the man and the woman are perfect substitutes, it does not matter who puts in what and in what order, only the total is of relevance. The concavity of the revenue function follows from the assumption of decreasing marginal return to labor effort (for given amounts of other factors), irrespective of who supplies the labor.

5.2. The Intra-Family Division of Labor

In the case depicted in Figure 6, the optimal input of household labor activity is A_h^*, which means that the ***joint minimum calorie intake*** is C_h^*. With this work activity, the feasible consumption of non-calories is at a maximum corresponding to **ed** (whether this is taken out in the form of leisure or consumption of non-calories, we leave

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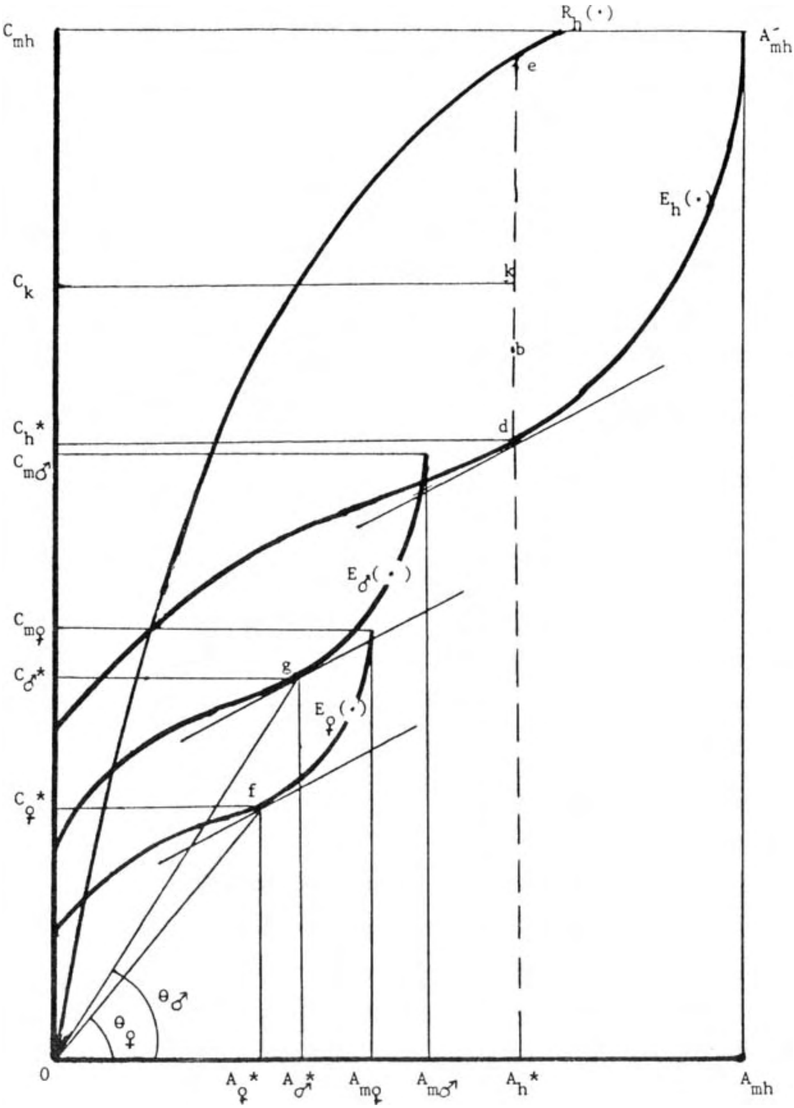
[14] The $E_h(\cdot)$ curve traces out the minimum amount of calories the two individuals need to jointly accomplish a given level of external (work) activity. The geometrical aggregation of $E_{♂}(\cdot)$ and $E_{♀}(\cdot)$ into $E_h(\cdot)$ can be done in the same way Meade (1952) constructed his two country production set in 'A Geometry of International Trade'. The more formal correspondence between the three curves will become evident as we proceed.

Figure 6



C_{mh}
$R_h(\cdot)$
A'_{mh}
e
$E_h(\cdot)$
C_k
k
b
C_h^*
d
$C_{m♂}$
$E_♂(\cdot)$
$C_{m♀}$
g
$C_♂^*$
$E_♀(\cdot)$
$C_♀^*$
f
$\theta_♂$
$\theta_♀$
0
$A_♀^*$
$A_♂^*$
$A_{m♀}$
$A_{m♂}$
A_h^*
A_{mh}

aside). The question is how the optimal joint work activity should be allocated between the man and the wife. The answer is simple: the optimal distribution must be where the marginal cost of a unit of labor activity in terms of calories expended is the same for the two and, thus, for the household. In Figure 6, this means at the points where the slope of the man's and the wife's expenditure functions is the same as at point **d** on the joint, household, expenditure function. This is at **g** and **f**, respectively.[15]

5.3. The Intra-Family Distribution of the Calorie Intake

It is notable that the optimal distribution of calories between the man and the wife is not that each should have equally much, neither in absolute terms, nor relative to the work effort they put in (other then as special cases). The calorie distribution that is consonant with the highest possible economic return to the household in the case shown in Figure 6 implies that the man gets more calories than the woman in absolute terms ($C_{\male}^*$ compared to $C_{\female}^*$). This is partly an effect of the assumption that he has a larger body mass and, thus, higher BMR (the intercept of the his expenditure function is larger than the woman's) and partly because he has a higher (maximum) physical work capacity. The man also gets more calories per unit of work effort expended than the woman (the angel $\theta_{\male} > \theta_{\female}$).

If intra-household 'discrimination' is implied when one of the two gets less food than the other in relation to their ***marginal*** work effort, there are no economic incentives for this to happen. It is easily seen

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15 It should be noted that by the construction of the $E_h(\cdot)$ curve, the sum of the vectors **g** and **f** is **d**. That is, $E_h(\cdot)$ combines the sum of all the points on the man's and the woman's expenditure functions where the slopes of these two functions are identical.

in Figure 6 that any other allocation than $C_{♂}*$ and $C_{♀}*$ will reduce the economic surplus. Assume that the man gets a little more than this, and the woman a little less, of the joint calorie intake that is consonant with the maximum economic surplus (C_h*). The additional work activity the man can exert with the extra calories he receives is smaller than the corresponding reduction of work activity for the woman. This implies that they (the household) would no longer be on the household minimum expenditure function, $E_h(\bullet)$, but at an 'interior' point such as **b** in Figure 6. The man who does not consider a high own body weight an objective, will thus not gain by trying to starve his wife and have her live with a body weight below that corresponding to the point **f** on her expenditure function. This would only reduce the economic surplus attainable to the family and, thus, himself. This is not to say that he might not want to discriminate the woman when it comes to the division of the non-calorie consumption, but not in terms of food (calorie) intake. However, if 'discrimination' is defined as an unequal calorie intake in relation to the *average* work effort supplied, the woman is discriminated in the case shown in Figure 6.

5.4. The Optimal Male/Female Body Weight Ratio

In constructing the household version of the model, it was assumed that the male and female calorie expenditure-weight functions have identical shapes, but that the male one is somewhat larger, i.e. a 'magnification', or blow-up, of the female one. This assumption was based on the fact that, throughout the world, men are some 8-9 percent taller than women (Svedberg, 1989). Given this assumption, the optimal male/female body weight ratio can be deduced from the model. The optimal allocation of work effort for the household depicted in Figure 6 implies, as shown above, that the (shorter) wife will work closer to her maximum physical capacity than the man does to his. That the woman is relatively higher up on her calorie expenditure-weight function than the man also means that her optimal body weight is closer to the body weight that corresponds to her maximum physical work potential ($A_{m♀}$), as compared to the equivalent body weight of the man. That is, the model predicts that women in the economic setting considered will be somewhat closer to the body weights of females in nutritionally unconstrained populations than men to the equivalent male weights. (This proposition is tested on data from Sub-Saharan Africa in Svedberg, 1988.)

5.5. Including Dependent Children

Finally, a brief word on how dependent children come into the picture (i.e. children of an age when they do not contribute to **current** family income). The calories needed to support a child have to be taken from the 'economic surplus' (so far assumed to be used for leisure and non-calorie consumption). Assume that the family modelled in Figure 6 has one child of a size (age) requiring **dk** calories in order to develop normally. This family would thus have an income equivalent of **ke** to spend on non-calories. With additional children the surplus would be reduced accordingly. It is notable, however, that none of the marginal conditions that determine the optimal external activity level are changed with the introduction of dependent children. With or without children, the optimal work intensity of the household is the same.[16]

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[16] In an intertemporal setting, there is, of course, an argument for children as supporters at old age. Such inter-generational allocation of food is not easily represented in this static model.

6. NUTRITIONAL REQUIREMENTS

The model has so far been used to derive the optimal work activity and body weight of the individual (and the household) given the constraints he faces: the economic revenue function, the biological calorie expenditure function and health considerations. Since the body weight and the external (work) activity are assumed to determine the number of calories the individual needs to stay in nutritional balance, we can establish 'calorie requirement norms', which are derived ***endogenously*** in the model. Which one is appropriate depends on the underlying purpose with the norm. Subsequently, the type of ***exogenously*** derived 'calorie requirement norms' set up by the FAO/WHO are analysed.

6.1. Endogenous Calorie Requirement Norms

The Economic Survival Requirement. In the case shown in Figure 3, A_1 is the lowest work activity that the ***individual*** can pursue in order to stay in nutritional balance and earn enough income to buy the calories required for internal activity and the work itself. C_1 is thus the economic survival calorie requirement; at a lower activity level, his calorie expenditure will exceed his calorie revenue. There is thus no possibility that the reference individual can survive over the ***long run*** on less calories than C_1 in a world where he has to work to be entitled to food.

The economic survival calorie requirement will depend, not only on the physical characteristics of the individual and the biologically determined efficiency with which the body utilizes the energy contained in food (the location and shape of the calorie expenditure function). It will also depend on his economic productive assets, his own work productivity and prices (the economic revenue function). Since the values of the parameters entering the calorie expenditure and, above all, the revenue function, will differ considerably across individuals, geographical locations and over time, it will be almost impossible to set up calorie requirement norms that are applicable to large groups of people.

With the economic survival requirement norm, however, individuals who are 'undernourished' can be identified, not by trying to estimate their specific requirement and their actual food intake (the dietary approach), but through observations of their health and physical status. A body weight (for height) below what is considered safe for health, or signs of diseases that are known to be caused by a negative balance between the habitual energy intake and expenditure, is a ***necessary*** precondition for a person to be below the economic survival calorie norm. In fact, this norm is derived on the presumption that when an individual does not fulfill it, this must show up in anthropometric and/or clinical measures. Inadequate anthropometric or clinical performance is not ***sufficient*** to define an individual undernourished, however, since the reason can be illness unrelated to nutrition.

The Biological Survival Requirement. A human biologist may be interested in the minimum energy requirement the individual has for internal body functions and the lowest external activity and body weight that is consistent with health. In terms of Figure 3, this would be C_h if the minimum external activity for maintaining health is A_h and the corresponding body weight W_h is consonant with long-term health. To find out what the 'biological' requirement is, can be of practical importance under some circumstances, e.g. to ration scarce food in a famine situation or to decide on food portions in hospitals when there is a severe budget constraint. In most situations, however, other 'requirement' norms are needed.

6.2. Exogenous Calorie Requirement Norms

Decent Life Requirement. It may seem desirable that a nutritional requirement norm should be set at a level that does not only ensure 'economic survival' in the narrow sense just discussed, but also allows for a work activity that produces a 'surplus'. The size of the surplus can be based on some notion of what constitutes a bare minimum for a 'decent life' or human 'basic needs', such as shelter, clothing and medical care. A 'decent-life' or 'basic-needs' requirement is easily represented in the present model. Say that the reference individual should have an economic surplus equal to b'n' in Figure 3. His 'basic-needs' calorie requirement is then C_{bn}, which is enough for his energy needs for internal activities and to work enough to earn the stipulated surplus b'n'.

Although it is true that 'men does not live from bread alone', there are certain problems with the interpretation of a 'basic needs' calorie requirement norm. First, a person who does not fulfill such a requirement is not necessarily undernourished in a biological, medical or clinical sense. Assume that the (optimal) external activity level, which the reference individual has chosen, lies somewhere between A_1 and A_{bn} in Figure 3 and that he is in nutritional balance. Since his actual energy intake falls below C_{bn}, he is undernourished according to the basic needs norm. He has a weight that is consonant with long-term health, however, and his external activity is above what is needed for body fitness. He also earns an income large enough to provide a small non-calorie consumption surplus. He would be clinically undernourished only if his ***preferences*** are such that he chooses some degree of undernutrition (i.e. choose to be in nutritional imbalance or in balance at a too low weight) in order to be able to consume more than b'n' of non-calories in the short term (over the long term, as was shown above, this is not feasible).

All this means that a calorie requirement based on the notion of a 'decent-life' or 'basic-needs' fulfillment is not first and foremost a device for identifying undernutrition. An individual who falls below this requirement may or may not be undernourished in the clinical sense. Instead, a 'basic needs' calorie requirement norm will serve as a '***poverty line***'. To set up poverty lines is, of course, a fully legitimate endeavour that can serve many worthwhile purposes, but it seems useful to distinguish the concept of undernutrition from that of poverty (although they are intimately linked). Not all very poor people are undernourished in a medical sense and some undernourished people are not very poor (however defined).

Even though 'calorie requirement' may be a valid criterion on which to base a 'poverty line' (cf. Lipton, 1983), there is the inescapable problem of ***where*** to draw the line. This unavoidably involves normative judgment of what constitutes a decent life and what the most basic needs are. This will differ from place to place and time to time depending on average income levels, the prevailing egalitarian objectives and a thousand other normative considerations. A calorie requirement based on 'basic needs' can thus not be derived with scientific methods in the Popperian sense. That is, we cannot hope to be able to define and estimate basic-needs calorie requirements that are 'true', universally applicable and free from value judgments.

Ability to Work Requirement. Yet another way of defining 'requirement' is to estimate calorie needs for predetermined, 'desirable', levels of external physical (work and social) activity. This is, in fact the way the FAO/WHO traditionally have proceeded in their estimation of 'recommended calorie requirement' (RCR). These estimates are based on, firstly, the biological requirement for BMR and other 'baseline' internal activities and, secondly, a predetermined amount and intensity of external activity.

Whether a specific individual's actual calorie intake meets this expenditure norm has, of course, nothing to do with whether he is undernourished or not. Many people with a calorie intake far below the FAO RCR norm will not be undernourished in the medical and clinical sense because of lower energy expenditures. Other people may be undernourished even though they have intakes well above the FAO calorie norms because they have to work long hours in heavy physical activities in order to earn a meagre living.

There is thus no appalling reason to think that an ability-to-work requirement should be an efficient means of delineating the clinically undernourished from the well-nourished. Rather, the method is apt to produce biased results when applied to individuals. A priori one would believe that, ***in general***, the poorest people have to work the hardest in physical activities in order to survive in a biological and economical sense. They would thus be the ones with the highest calorie expenditures and the most likely to be clinically ***undernourished*** even with an actual intake ***above*** the norms recommended by the FAO. The not-so-poor and the (relatively) rich are likely to be involved in less demanding physical work activities ***on the average*** and, thus, have a lower expenditure. They thus stand a high probability to be wrongly classified as 'undernourished' with the FAO RCR norm. The use of RCRs based on predetermined and standardized work activity levels mean that there will be a ***built-in tendency to classify the undernourished as well-nourished and vice versa***.

When applied to large groups of people, there is no a priori reason to think that the errors should cancel out so as to produce an unbiased estimate of the incidence of undernutrition in the group as a whole. The main problem lies in the FAO/WHO assumption that the ***average*** adult man in the developing countries has to work 2,555 hours per year in moderately heavy physical activities in order to avoid undernutrition in the family. However, if 2,555 hours per year is what the average male adult has to work to earn the minimum income needed to cover the family's food energy requirements, one wonders how the 50 percent of the population, which has a productivity and income below the average, can survive. If one is to trust the income distribution estimates reported by the World Bank (1987, appendix table 26), the poorest half of the households in countries like Kenya, Zambia and Cote d'Ivoire have about 15 percent of total national incomes. The 20 percent poorest households are estimated to earn less than one-fifth of the average income.

Now, how can the poorest 20 percent of the households cope with less than one-fifth of the income of the average household, in which the man has to work for 2,555 hours per year in medium heavy physical activity just to earn the calories needed to avoid undernutrition? Under the presumption that the poorest households have already done what is possible to adjust body weight and physical external activity in line with the predictions of the model derived earlier, they would only be able to get command of about one-fifth of food energy that the average household consumes, a household which is barely making it out. At one-fifth, or for that matter, any consumption level below what is required for the 'average' household, cannot be sustainable by the very definition used by the FAO/WHO. Fifty percent of the households would simply be undernourished, and a substantial share severely so. *In these* households the incidence of anthropometric and clinical signs of undernutrition must be very high. The mortality rate in the 20 percent poorest households must be astronomical. (These notions are tested on a large data set from Sub-Saharan Africa in Svedberg, 1989.)

To be fair, the FAO has often pointed out that the RCRs should only be used for ***prescriptive*** purposes, not for ***identifying*** undernourished individuals or groups of individuals. The organization has not always been consistent, however. In its annual publication ***The State of Food and Agriculture***, the estimated per capita availability of calories in the various countries was expressed as a ratio of the country-specific per-caput RCR up to 1985. The main problem is, however, that so many others have used the RCRs to identify undernourished individuals or to estimate undernutrition within groups. There are thousands of sample studies based on this approach (cf. Schofield, 1979); the World Bank (1986) has gone as far as to estimate the 'prevalence' of undernutrition on a global scale, using the FAO RCR norms.

7. CONCLUDING REMARKS

The model developed in this paper shows the optimal ***work effort*** and ***body weight*** of individuals in nutritionally constrained populations to be below what is normal in the rich and well-nourished parts of the world. A low work intensity and a small body size are not necessarily signs of weakness and undernutrition, but adjustments which are conducive to economic productivity. However, the model also shows it to be dangerous for the nutritionally constrained individual not to have considerable energy reserves stored in the own body when there are fluctuations in prices and productivity, and where financial (or other) savings and credit are non-existent (or very expensive). A decummulation of body reserves may put the individual in a 'poverty trap' from which there is no escape, or, at worst, in an 'undernutrition trap', which may be fatal without outside assistance. There is thus a trade-off between productivity and food security (which should be given more attention in future research).

In the household version of the model, it was shown that in the economically optimal equilibrium, the division of labor and calorie intake within the family usually implies 'inequalities' between men and women. The model also predicts that men and women in nutritionally constrained populations will have different body weights (for height) in relation to what is normal in populations where basic nutrition is not an economic consideration. This, however, is not necessarily a sign of 'discrimination'; they may well be economically well-motivated differences that are beneficial for the household at large.

The model further suggests that the establishment of calorie requirement norms based on exogenously determined fixed amounts of work activity will produce biased results when used to estimate the prevalence of undernutrition. There will be a built in tendency to classify the wellnourished individual undernourished and vice versa. When used to estimate the incidence of undernutrition in groups of people, the estimates will be upward biased. This hypothesis is tested and vindicated in the Sub-Sahara African context in Svedberg (1989).[17] The implication of this finding is that although far from satisfactory, the food situation in this region is far less serious than purported by the international organizations.

The model further predicts that in the kind of economic activities that dominate in Sub-Saharan Africa, i.e., non-mechanised agricultural production based on family (unskilled) labor, the optimal intra-household division of labor implies that women work more intensively (in relation to the calorie intake) and have higher body weights (for height) than men. The latter notion is corroborated by tests on the basis of almost 50 different populations in more than a dozen Sub-Saharan Africa countries in Svedberg, 1988. By anthropometric standards, women are thus at an advantage vis a vis men in Sub Saharan Africa.

[17] The tests are conducted mainly by comparing the FAO and IBRD estimates of the percentage of the population in Sub-Saharan Africa which suffers from undernutrition according to anthropometric sample studies. A very large set of such studies show the percentage of the sample populations that fall below the standard cut-off points to be considerably smaller than the estimates provided by the international organizations. Preliminary findings were reported in Svedberg (1987).

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