On the Economics of Food and Nutrition

by

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Abstract: This paper explores the relationships between food consumption, nutrition and investment. It examines the linkages between malnutrition and the incentive to invest and accumulate capital. The analysis focuses on a dynamic model where preferences about the future depend on nutrition and health. Situations of malnutrition cover both ends of the spectrum: from nutrient deficiency to obesity. The model involves preferences that are not time-additive and exhibit endogenous discounting. This provides a framework to investigate the factors affecting consumption and investment behavior. In this context, the adverse investment incentives of malnutrition are examined, with implications for economic policy.

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1. Introduction

Malnutrition issues have always been a subject of concern. With a world population now exceeding 6.5 billion people, feeding the growing human population remains a significant challenge. Over the last few decades, technological progress and the intensification of agriculture have generated a sharp increase in world food production. This increase has been large enough to allow feeding an adequate diet to every human on earth (e.g., Runge et al.; Sachs, 2005) and has contributed to a reduction in the real price of food. Yet, malnutrition problems persist in developed as well as developing countries. They are often associated with income distribution issues: chronic hunger results from extreme poverty when the income of poor households is too low to support an adequate diet. Chen and Ravallion have estimated that 1.1 billion people lived in extreme poverty in 2001 (down from 1.5 billion in 1981), most of them living in developing countries. In extreme situations, the purchasing power of the poor is below a minimal subsistence level, leading to starvation and death (e.g., Glomm and Palumbo; Sen). In less extreme situations, poverty can lead to insufficient food intake and nutrient deficiencies (including energy, proteins as well as micronutrients), with adverse effects on productivity and welfare (e.g., Dasgupta and Ray; Strauss and Thomas; Wheeler; Zimmerman and Carter). However, malnutrition is not limited to nutritional deficiencies. At the other extreme, it also includes excessive food intakes leading to obesity and heath problems. Obesity issues are found in every country and are becoming more severe. The World Health Organization calls obesity a "global epidemic." In the USA, the percentage of adults who are either overweight or obese has increased from 38 percent in 1976-1980 to 65 percent in 1999-2002. During the same period, the percent of adults considered obese increased from 15 percent to 31 percent (Center for Disease Control) and children's obesity rates tripled to reach 15 percent (Anderson et al.). Persons who are overweight are at increased risk for heart disease, high blood pressure, diabetes, arthritis-related disabilities, and some cancers. In addition to medical expenses, the cost of obesity includes workdays lost, disability pensions, loss of wages and productivity, and premature mortality. It has been estimated that the annual cost of obesity and overweight in the USA exceeds $100 billion (Wolf and Colditz; Finkelstein et al.).

The nutritional status of individuals depends on their food intake (along with their genetics and the physiology on human nutrition). In this context, understanding malnutrition requires understanding food consumption behavior. The effects of prices and income on food consumption have been studied extensively. It is well understood that there is a minimal purchasing power below which a household cannot support an adequate diet for its members (e.g., Dasgupta and Ray; Glomm and Palumbo; Sen; Wheeler). This makes it clear that insufficient income is an important cause of hunger and nutrient deficiencies. However, low income is only one of the factors contributing to malnutrition. For example, it cannot explain the observed rise in overweight problem among low-income adults and children (e.g., the case of American Indians; see Story et al.). And obese individuals can be found in every socio-demographic group and at every income level (Center for Disease Control; Sundquist and Johansson; World Health Organization; Zhang and Wang). This indicates that the determinants of malnutrition are complex. This raises a significant challenge to our economic understanding of malnutrition: How can we explain the presence of malnutrition among the poor as well as the non-poor? What are the causes of the current obesity epidemic? Technological change is one of the contributing factors. In particular, technological progress in agriculture has reduced the cost of food and nutrition, thus stimulating calorie intake and contributing to the growth in obesity (Philipson and Posner). Lakdawalla and Philipson have estimated that 40 percent of the recent growth in weight is due to lowered food prices. This means that remaining 60 percent is due to other factors. They include changes in home technology and food marketing. Such changes contributed to the adoption of more sedentary lifestyle and a reduction in physical activities and calorie expenditures. They also contributed to lowering the time cost of food preparation and cooking which, together with an increase in the number of women entering the labor force, stimulated a reliance on “food away from home” and “fast food” (Guthrie et al.; Chou et al.). Yet, it is not clear whether more “eating out” is a causal factor since restaurants can cook low-calorie food just as easily as high-calorie food (Cutler et al.). This leads to the fundamental question: why would any individual choose to become obese? Rational individuals decide how much food to consume on the basis of tastes, prices and income, accounting for the anticipated future health consequences of their actions. Many factors play a role, including lifestyle and genetics. In general, weight control requires one to forego current consumption in order to gain future potential health benefits. Since there is extensive information on the relationship between health and nutrition, this suggests that individuals who become obese must heavily discount the future (Becker and Mulligan; Ehrlich and Chuma; Fuchs, 1986, 1991; Komlos and Bogin). This creates a fundamental challenge to the standard economic model where discounting the future is typically done at a constant rate (e.g., Samelson; Deaton and Muellbauer). There is strong evidence that time discounting is not constant over time and that it varies across individuals (e.g., Frederick et al.). At this point, there is a need to refine our understanding of the linkages between malnutrition issues and time discounting.

The objective of this paper is to take a new look at the economics of food and nutrition. We explore the adequacy of standard economic models in addressing nutrition issues and their linkages with investment and capital accumulation. We build on the intuitive and strong relationships that exist between food consumption, nutrition, and health. We examine the linkages between malnutrition and the incentive to invest and accumulate capital. We argue that such linkages have been somewhat unexploited in economic analysis. This is important to the extent that accumulations of physical and human capital are a crucial part of the process of economic growth. One of the main insights developed in the paper involve the effects of nutrition on discounting the future. The basic idea is simple: if malnutrition is associated with heavy discounting of the future, this heavy discounting also provides a disincentive to invest, thus reducing the prospects for capital accumulation. Note that such effects go beyond the short term effects of malnutrition on labor productivity. Our analysis provides some new hypotheses about the factors affecting economic behavior. It points to new directions that can help refine our understanding of consumption and investment behavior. Our investigation also gives new insights into policy analysis.

2. Conceptual Approach

Much research has been conducted on food demand. The impact of income and prices on food consumption behavior is now reasonably well understood (e.g., Huang, Wohlgenant, and others). It is typically based on neoclassical consumer theory, which provides useful guidance on incorporating economic rationality into empirical modeling of consumer behavior (e.g., Deaton and Muellbauer). Typically, the analysis is presented at the household level. This reflects the fact that the household is the basic micro unit for decision making. The household-level approach potentially neglects intra-household decision rules and transfers that can affect consumption and investment decisions. This creates a dilemma for modeling economic behavior: while many decisions are made at the household level, nutritional status must be assessed at the individual level (e.g., nutritional achievements can vary among individuals in the same household). Since we focus our attention on the economics of nutrition, the analysis below is developed at the individual level.

Here, we emphasize the strong and intuitive relationships that exist between food intake and health. This is very basic: on the one hand, individuals cannot survive without eating; on the other hand, excessive food intake has adverse effects of individual health. Food being a necessity has been properly emphasized in the economic literature on famines. For example, Sen has argued that famines take place when the purchasing power of households falls short of satisfying the nutritional needs of individuals. However, the economics of obesity is still poorly developed. It is known that excessive eating has adverse effects on health. If so, why is obesity such a serious and growing problem? The issue is complex and involves genetics, nutritional education, information as well as lifestyle. One key question is: Why are obese consumers not anticipating the adverse health effects of their consumption decisions? We investigate this problem by looking at both consumption and investment behavior. Our analysis of investment behavior necessitates the development of a dynamic model. This requires some careful thinking about the linkages between food intake and health in the analysis of intertemporal allocation decisions.

Consider an individual making decisions over a T-period planning horizon. At each time period, decisions are made on three sets of variables: consumption goods represented by the vector x_t; the individual's physical and human capital denoted by the vector k_t; and a vector y_t representing other "state variables" at time t. Let $x_t = (x_{ft}, x_{ot})$ where x_{ft} denotes food consumption and x_{ot} denotes non-food consumption. The capital goods k_t evolve over time according to the state equation

$$k_{t+1} = f_t(k_t, \cdot) + z_t, \tag{1a}$$

where z_t is the investment (or disinvestment if negative) made at time t, t = 1, 2, …, T. In general, $[f_t(k_t, \cdot) - k_t]/k_t$ is the natural growth rate of capital (or depreciation rate if negative) at time t. When negative, z_t can represent asset liquidation as well as borrowing in the capital markets. Let $Z(k_t)$ denote the feasible set for z_t. We allow the feasible set $Z(k_t)$ to depend on capital k_t. With $z_t \in Z(k_t)$, this can represent the functioning of the capital markets. For example, situations of credit rationing can be represented by $Z(k_t) \subset Z(k_t')$ for $k_t < k_t'$, where asset-poor individuals have limited borrowing capacity.[1]

The state variables y_t include individual health as well as individual memory. Letting y_t capture health effects will be of special interest to represent the strong linkages between health and nutrition. Indeed, we expect two-way interactions between consumption and health: food consumption affects nutrition and individual health; and health influences how the individual enjoys consumption goods. More generally, the variables y_t can also characterize the individual's memory, habit formation, or information processing (which influences the dynamics of consumption decisions and of advertising). The state variables y_t evolve over time according to the state equation

$$y_{t+1} = h_t(y_t, x_t), \tag{1b}$$

t = 1, 2, …, T. At time t, equation (1b) is a difference equation showing the dynamic determination of the state variables y_{t+1} given y_t and x_t.[2] We will assume that $\partial h_t/y_t \neq 0$ and $\partial h_t/\partial x_t \neq 0$ for some x_t. This means that there exist dynamics in the state variables y_t (e.g., health dynamics) and that their trajectory is affected by individual consumption x_t (e.g., food consumption affects nutrition and individual health).

At time t, the capital k_t generates a gross return denoted by $g_t(k_t, \cdot)$. Let $p_t > 0$ denote the column vector of market prices for consumer goods x_t,[3] and $q_t > 0$ be the column vector of prices for investments z_t. The budget constraint at time t is

$$p_t^T x_t \leq g_t(k_t, \cdot) - q_t^T z_t, \tag{2}$$

where the superscript "^{T}" denotes the transpose. This states that consumer expenditures ($p_t^T x_t$) cannot exceed gross income $g(k_t, \cdot)$ minus investment cost ($q_t^T z_t$).[4]

We focus our attention on health and nutrition. Since good nutrition is a necessary part of good health, we explore the dynamic linkages between food consumption and health. When y_t reflects health, equation (1b) allows the evolution of individual health to depend on previous health and current food consumption. Assume that individual preferences over a T-period planning horizon are represented by the classical time-additive utility function[5]

$$u(x_1, y_1, \ldots, x_T, y_T) = \sum_{t=1}^{T} u_t(x_t, y_t), \tag{3}$$

where $u_t(x_t, y_t)$ is the (discounted) utility obtained at time t. Note that equation (3) allows the state variables y_t to interact with the consumption bundles x_t in the utility function. This can be interpreted as follows: when y_t reflects individual health at time t, equation (3) allows the marginal utility of consuming x_t to depend on the individual health y_t. A common specification in (3) is $u_t(x_t, y_t) = D(t)\, u(x_t, y_t)$, where D(t) is a discount factor satisfying $0 < D(t) < 1$. When $D(t) = \beta^t$, this generates the standard discounted utility model under "exponential discounting" where $\beta \in (0, 1)$ is a constant discount rate (first proposed by Samuelson). When $D(t) = (1 + \alpha\, t)^{-\gamma/\alpha}$ with $\alpha > 0$ and $\gamma > 0$, this corresponds to a hyperbolic discount (Loewenstein and Prelec). And when $D(t) = \delta\, \beta^t$ with $\delta \in (0, 1]$ and $\beta \in [0, 1)$, this corresponds to a quasi hyperbolic discount (Laibson). Equation (3) represents most models of economic behavior found in the literature (including models of rational addiction developed by Becker and Murphy, and Becker et al.).

The individual makes consumption decisions x_t and investment decisions $z_t \in Z(k_t)$, $t = 1, \ldots, T$. We assume that the functions $f_t(k_t, \cdot)$ in (1a), $h_t(y_t, x_t)$ in (1b) and $u_t(x_t, y_t)$ in (3) are twice continuously differentiable. Under the utility function (3), economic rationality implies that individual decisions are made in a way consistent with the dynamic programming problem

$$G_t(k_t, y_t) = \text{Max}_{x_t, z_t} \{u_t(x_t, y_t) + G_{t+1}[f_t(k_t, \cdot) + z_t, h_t(y_t, x_t)]$$

$$: \text{equation (2)}, x_t \in X, z_t \in Z(k_t)\}, \tag{4}$$

where $G_t(k_t, y_t)$ is the value function at time t = 1, …, T, with $G_{T+1} = 0$. At time t, optimal consumption and optimal investment are the solution of the optimization problem (4): $x_t^{\#}(p_t, q_t, k_t, y_t)$ and $z_t^{\#}(p_t, q_t, k_t, y_t)$, respectively. This provides a generic way of investigating the properties of consumption and investment behavior.

Unfortunately, while observations can be made on x_t, z_t, p_t, q_t and k_t, measuring the state variables y_t is often problematic in economic analysis. For example, when y_t represents the individual's memory, this information is difficult to measure and typically not available to researchers. Similarly, when y_t measures health, assessing individual health status can be difficult for at least two reasons. First, individual knowledge about their specific health status may be poor. Second, the diagnosis of some medical conditions can be difficult (e.g., they may require refined medical examinations). As a result, assessing individuals' health status is often problematic and refined measurements of y_t are typically not available. Without complete observations on y_t, empirical analysis of the behavior rules $x_t^{\#}(p_t, q_t, k_t, y_t)$ and $z_t^{\#}(p_t, q_t, k_t, y_t)$ becomes more challenging. One option is to treat the y_t's as unobserved random variables and to estimate the corresponding means $\mu_{xt}(p_t, q_t, k_t) = E_y[x_t^{\#}(p_t, q_t, k_t, y_t)]$ and $\mu_{zt}(p_t, q_t, k_t) = E_y[z_t^{\#}(p_t, q_t, k_t, y_t)]$ where E_y is the expectation operator over the random variables y_t. Note that the dynamics of y_t in (1b) will typically imply serial correlation, which can in principle be handled econometrically. However, the linkages between serial correlation in econometric models and economic theory are often weak. This makes it difficult to provide a precise interpretation of estimated serial correlation for economic behavior. This suggests a need to explore some alternative specification to (4).

3. A Reduced Form Model

Consider that $u(x_1, y_1, \ldots, x_T, y_T)$ in (3) gives a structural representation of preferences. Then, equation (4) provides a "structural approach" to microeconomic analysis. As just discussed, if y_t is not observable, we look for an alternative specification to equation (4) that preserves strong linkages between theory and applied work. The simplest way to do this is to make use of a "reduced form" representation for y_t in (3) and (4). This is the approach explored in this section.

The first step toward a reduced form approach related to y_t is to use successive substitution and rewrite equation (1b) as

$$
\begin{aligned}
y_{t+1} &= h_t(h_{t-1}(h_{t-2}(\cdots), x_{t-1}), x_t), \\
&\equiv h_t'(x_1, x_2, \ldots, x_t; y_1),
\end{aligned}
\tag{1b'}
$$

$t = 1, 2, \ldots, T$. Then, substituting (1b') into the utility function in (3) yields

$$
\begin{aligned}
u(x_1, y_1, \ldots, x_T, y_T) &= \sum_{t=1}^{T} u_t(x_t, h_{t-1}'(x_1, x_2, \ldots, x_{t-1}; y_1)), \\
&\equiv v(x_1, x_2, \ldots, x_T; y_1),
\end{aligned}
\tag{3'}
$$

where $v(x_1, x_2, \ldots, x_T; y_1)$ is a "reduced form" utility function, which depends on all consumption decisions $(x_1, x_2, \ldots, x_T)$ and on the initial states y_1. In general, one can expect the initial states y_1 to vary across individuals (e.g., due to genetic differences or different childhood experiences). This can help explain the presence of significant heterogeneity in preferences across individuals. But for a given y_1, the preference function $v(\cdot)$ in (3') depends only on the stream of consumption goods $(x_1, x_1, ..., x_T)$, and <u>not</u> on $(y_2, \ldots, y_T)$. It has two desirable properties: 1/ it is theoretically valid; and 2/ it does not require explicit measurements of the states y_t at time $t = 2, \ldots, T$. Note that most utility specifications found in the literature exhibit this latter property (e.g., Deaton and Muellbauer; Deaton). This suggests that the reduced form specification (3') has provided the standard basis for empirical analyses of consumer behavior. However, the dynamic specification of $v(x_1, x_2, \ldots, x_T; y_1)$ in (3') has received less attention.

Note that the marginal utility of consumption x_t in (3') is $\partial v/\partial x_t$. In general, this marginal utility depends on all consumption decisions $\mathbf{x} = (x_1, x_2, \ldots, x_T)$ and on the initial state y_1. For $t \neq t'$, define R(t, t', **x**) ≡ rank[$\partial^2 v/\partial x_t \partial x_{t'}$] as the rank of the matrix of cross-derivatives of the utility function v(·) with respect to x_t and $x_{t'}$.

<u>Proposition 1</u>: Assume that $\partial u_t/\partial y_t \neq 0$, $\partial h_t/\partial y_t \neq 0$ for some y_t, and $h_t(x_t, \cdot)$ is a non-linear function of x_t.

Then,

a. the "reduced form" utility function <u>cannot</u> be time-additive.

b. $1 \leq R(t, t', \mathbf{x}) \leq n$ for some **x**, $t \neq t'$, where n is the number of commodities in x_t.

Proposition 1 involves some mild regularity conditions. When y_t represents health, they are that health affects utility ($\partial u_t/\partial y_t \neq 0$); that health exhibits significant dynamics ($\partial h_t/\partial y_t \neq 0$ for some y_t); and that health is a non-linear function of consumption x_t. This last condition can be motivated as follows. In general, increasing food intake is expected to improve individual's nutritional status and health when food consumption is low (e.g., in situations of hunger), but to worsen individual health if food consumption is very high (e.g., leading to obesity). In this case, the function $h_t(x_t, \cdot)$ would be increasing (decreasing) in x_{ft} when x_{ft} is low (very high), implying a non-linear relationship.

Under these mild regularity conditions, Proposition 1 states that the reduced form utility $v(x_1, x_2, \ldots, x_T; y_1)$ in (3') cannot be time additive. The reason is intuitive. A time additive model implies that marginal utility of consumption x_t at time t is independent of consumption at any other time. But if health affects utility and exhibits dynamics, and if nutrition has a nonlinear effect on health (as stated in the regularity conditions), then $\partial v/\partial x_t$ cannot be independent of consumption $x_{t'}$ for all $t \neq t'$. This shows that a time additive specification for v(·) in (3') is inadequate to capture the linkages between food and health.

In view of Proposition 1, it is interesting to note how prevalent time-additive utility specifications have been in the literature. For example, Deaton has used such a specification to gain insights into the dynamics of consumption behavior and the implications of economic rationality for "consumption smoothing". While convenient, time-additive specifications have a significant drawback: they neglect fundamental linkages between food intake and human health. Indeed, it is clear that both very low and very high food consumptions have adverse effects on health and the long term quality of life. If we want to take such issues seriously, current food consumption *must* affect the marginal utility of future consumption. While such effects can be captured in the structural utility (3) (through the state variable y_t), they require a departure from time-additivity under the reduced form utility (3'). This implies that, by being inconsistent with basic nutrition, the standard time-additive model is inappropriate in the context of (3'). This suggests a need to rely on a less restrictive model that can better represent the strong linkages that exist between food, nutrition and health.

It is well understood that a minimum of food intake is required for individual survival. Define the starvation set X_s as the consumption set that does not meet this minimum nutritional requirement. Define X_a as the set of individual food intake that is viewed as adequate by nutritionists. And define X_o as the consumption set that is viewed as involving "excessive food intake" by nutritionists (in the sense of leading to obesity and its adverse health effects). In general, as food intake x_{ft} increases, an individual can move from the starvation set X_s to the adequate set X_a to the obesity set X_o. Let $y_t \in [0, 1]$ denote a health index for the individual at time t, where $y_t = 1$ represents perfect health, and $y_t = 0$ represents death. From equation (1b), the irreversibility of death means that, $x_t \in X_s$ implies $y_{t+i} = 0$ for all $i \geq 1$. Assume in addition that $u_t(x_t, 0)$ is independent of x_t (as enjoying consumption requires a positive amount of health). Then, $\partial v/\partial x_{t'} = 0$ if $x_t = (x_{ft}, x_{ot}) \in X_s$ and $t' > t$. Alternatively, consider some consumption $x_t'' \in X_a$ satisfying $x_t'' \geq x_t$. Since getting out of the starvation set requires more food, it follows that $x_{ft}'' > x_{ft}$. Under non-satiation, as long as the individual survives up to period t', we can expect that $\partial v/\partial x_{t'} > 0$. Thus, increasing food intake from x_{ft} to x_{ft}'' implies that $\partial v/\partial x_{t'}$ increases from zero for $t' > t$. In addition, consider consumption $x_t''' \in X_o$, with $x_{ft}''' > x_{ft}''$. Being in the obesity set, the associated adverse health effects of obesity are expected to reverse the above results. In other words, increasing food intake from x_{ft}'' to x_{ft}''' implies that $\partial v/\partial x_{t'}$ can be expected to decrease for $t' > t$. These results are summarized next.

Proposition 2: For t' > t, the marginal utility $\partial v/\partial x_{t'}$ first increases with x_{ft} (for low levels of food intake x_{ft}), then decreases with x_{ft} (for high levels of food intake x_{ft}).

Proposition 2 provides useful information about the properties of marginal utility under reduced form preferences (3'). It states that food consumption at time t, x_{ft}, is expected to affect the future marginal utility of consumption, $\partial v/\partial x_{t'}$ with t' > t. This effect is generated by the linkages between food consumption, nutrition, and health. On the one hand, this is just another way of stating that the reduced form utility $v(\cdot)$ in (3') cannot be time-additive. On the other hand, this provides information on the nature of non-additive preferences for $v(\cdot)$. This information can help us choose a specification for the reduced form utility $v(\cdot)$ in (3').

3.1. A Specification of Dynamic Preferences

As just argued, nutritional considerations indicate that the reduced form utility (3') cannot be time additive. The next challenge is to specify a non-additive form for (3') that can capture nutrition effects. Can it be done without invalidating the basic backward induction scheme underlying the Markovian approach to dynamic programming? The answer is yes, in the context of recursive preferences. Taking y_1 as given in equation (3'), let $V_1(x_1, x_2, \ldots, x_T) = v(x_1, x_2, \ldots, x_T; y_1)$. Following Koopmans, and Koopmans et al., we consider the recursive specification of intertemporal preferences

$$V_t(x_t, x_{t+1}, \ldots, x_T) = U_t(x_t, V_{t+1}(x_{t+1}, \ldots, x_T)), \tag{5}$$

where $U_t(x_t, V_{t+1}(x_{t+1}, \ldots, x_T))$ is increasing in x_t, $0 \le \partial U_t/\partial V_{t+1} < 1$, t = 1, …, T, with $V_{T+1} = 0$. Note that $\partial^2 V_t/\partial x_t \partial x_{t+1} = (\partial^2 U_t/\partial x_t \partial V_{t+1})(\partial V_{t+1}/\partial x_{t+1})$. In general, $\text{rank}[\partial^2 U_t/\partial x_t \partial V_{t+1}] \le 1$. This includes as a special case the time-additive utility function where $\partial^2 U_t/\partial x_t \partial V_{t+1} = 0$. As argued above, this appears inappropriate to capture the dynamics of nutrition. Below, we will focus our attention on the case where $\partial^2 U_t/\partial x_t \partial V_{t+1} \neq 0$ and $\text{rank}[\partial^2 U_t/\partial x_t \partial V_{t+1}] = 1$. Then, the utility function is <u>not</u> time-additive, as it allows the rank $R(t, t+1, \mathbf{x}) = \text{rank}[\partial^2 V_t/\partial x_t \partial x_{t+1}]$ to be equal to 1. Recall the result obtained in Proposition 1: R(t, t+1, $\mathbf{x}$) ≥ 1. The recursive specification (5) satisfies this condition. In general, equation (5) is the simplest recursive specification that that is not time additive and where R(t, t+1, $\mathbf{x}$) = 1. As such, it allows current food consumption to affect the marginal utility of future consumption, thus providing a framework to reflect nutrition and health issues.

Note how equation (5) captures the discounting of the future. The term $\partial U_t/\partial V_{t+1}$ is a marginal *discount factor*. It measures the marginal effect on current utility of obtaining one more util next period. We assume that this discount factor is bounded between 0 and 1, $0 \leq \partial U_t/\partial V_{t+1} < 1$. This means that the individual is in general concerned about the future, $\partial U_t/\partial V_{t+1} \geq 0$. It also means that it values the present relatively more than the future, $\partial U_t/\partial V_{t+1} < 1$. Finally, it allows for the discount factor $\partial U_t/\partial V_{t+1}$ to vary with economic conditions. Below, we emphasize the importance of this last characteristic. As noted above, equation (5) includes the time additive model as a special case when $\partial U_t/\partial V_{t+1}$ is a constant. Thus, recursive preferences (5) relax the assumption of a fixed discount factor. And, by endogenizing the discount factor, they provide a basis for exploring the linkages between food security and dynamic behavior.

As noted in Propositions 1 and 2, we expect low food consumption to affect how the individual views the future. In this context, Proposition 2 shows how food consumption x_{ft} can be expected to affect the marginal utility $\partial V_t/\partial x_{t'}$ for t' > t. Given $\partial^2 V_t/\partial x_t \partial x_{t+1} = (\partial^2 U_t/\partial x_t \partial V_{t+1})(\partial V_{t+1}/\partial x_{t+1})$ and assuming that $\partial V_t/\partial x_t > 0$ for all t, Proposition 2 yields the following Corollary:

Corollary 1: The discount factor $\partial U_t/\partial V_{t+1}$ first increases with x_{ft} (for low levels of food intake x_{ft}), then decreases with x_{ft} (for high levels of food intake x_{ft}).

Corollary 1 implies that, if food consumption x_{ft} is sufficiently low (corresponding to situations of severe hunger or starvation), the discount factor would be low, with $\partial U_t/\partial V_{t+1} \approx 0$. Alternatively, if food consumption x_{ft} is nutritionally adequate, then the discount factor $\partial U_t/\partial V_{t+1}$ would be higher. Finally, if food consumption x_{ft} is very high (e.g., corresponding to situations of obesity), the discount factor would be lower again. Note that this still allows the possibility that hunger and obesity might coexist (e.g., as commonly found among American Indians). This would occur when some individuals have a poor diet exhibiting high consumption of high-calorie food items combined with nutritional deficiencies in proteins or micronutrients.

With $x_t = (x_{ft}, x_{ot})$, Corollary 1 does not state how non-food consumption x_{nt} affects the discount factor. The reason is that most non-food items are not directly linked with individual health.[6] As a result, non-food consumption may not have a clear effect on how individuals perceive their future. This reflects the fact that Corollary 1 is largely motivated by the linkages between food, nutrition and health.

4. Consumption and investment behavior

In this section, we analyze the implications of recursive preferences (5) for consumption and investment decisions. One attractive characteristic of recursive preferences is that they allow backward induction to be implemented in a simple way. Indeed, using backward induction, optimal behavior is given by the functional equation (see Streufert, 1990, 1992; Becker and Boyd):

$$W_t(k_t) = \mathrm{Max}_{x_t, z_t} \{U_t(x_t, W_{t+1}[f_t(k_t, \cdot) + z_t]): p_t\, x_t \leq g_t(k_t, \cdot) - q_t\, z_t,\ x_t \in X,\ z_t \in Z(k_t), \tag{6}$$

where $W_t(k_t)$ is the value function at time t. Denote the optimal decision rules in (6) by

$$x_t^* = x_t^*(p_t, q_t, k_t) \tag{7}$$

for consumption, and by

$$z_t^* = z_t^*(p_t, q_t, k_t) \tag{8}$$

for investment.[7] They summarize how economic behavior responds to a changing economic environment.

In general, consumption and investment decisions are made jointly. Indeed, from the budget constraint, they must both compete for gross income $g_t(k_t, \cdot)$. However, the linkages between consumption and investment can be complex. Below, we explore two aspects of these linkages related to food and nutrition: how poor nutrition can affect productivity; and how nutrition can affect investment incentives.

4.1. Nutrition and labor productivity

There is empirical evidence that nutritional inadequacy has adverse effects on labor productivity (e.g., Behrman and Deolalikar; Haddad and Bouis; Strauss; Strauss and Thomas). In our model, these adverse effects can take place in two ways: through capital accumulation, and through income generation. With $x = (x_f, x_o)$, this suggests that food intake x_f can become an argument of the capital accumulation function $f_t(k_t, x_{ft})$ and of the income generation function $g_t(k_t, x_{ft})$. In the former case, the productivity effect would be in the longer term, as malnutrition can speed up the depreciation of physical and human capital. In the latter case, the productivity effect would be in the short term, as malnutrition reduces labor productivity and the capacity to generate current income. In general, one would expect the effects of x_{ft} on productivity to be present only in situations of significant nutritional inadequacy (when x_{ft} is either very low or very high). Alternatively, when food intake x_{ft} is nutritionally adequate, x_{ft} may cease to have any effect on f_t and g_t. This suggests that finding evidence that nutrition affects productivity requires data from individuals facing significant nutritional issues. Such effects can be expected to be important for individuals in extreme poverty or facing extreme obesity.

Consider the case where malnutrition has adverse effects on productivity through both capital accumulation f_t and income generation g_t. Under differentiability and assuming an interior solution, the first-order necessary conditions for (6) are

$$\partial U_t/\partial x_t + (\partial U_t/\partial V_{t+1})(\partial W_{t+1}/\partial k_{t+1})(\partial f_t/\partial x_t) = \lambda_t\, [p_t - \partial g_t/\partial x_t], \tag{9a}$$

$$(\partial U_t/\partial V_{t+1})(\partial W_{t+1}/\partial k_{t+1}) = \lambda_t\, q_t, \tag{9b}$$

where $\lambda_t > 0$ is the marginal utility of income. Equations (9a) and (9b) are standard marginal conditions. They state that, at the optimum, (discounted) marginal value must equal marginal cost. From equation (9a), the marginal value of consumption x_t is $[\partial U_t/\partial x_t + (\partial U_t/\partial V_{t+1})(\partial W_{t+1}/\partial k_{t+1})(\partial f_t/\partial x_t)]/\lambda_t$, while the corresponding marginal cost is $[p_t - \partial g_t/\partial x_t]$. If $(\partial f_t/\partial x_t) = 0$ and $(\partial g_t/\partial x_t) = 0$, this reduces to the neoclassical result:

$(\partial U_t/\partial x_t)/\lambda_t = p_t$,

where production/investment decisions are separable from consumption decisions (e.g., Deaton and Muellbauer; Singh et al.). This illustrates how the effects of malnutrition on productivity would alter neoclassical consumer theory. First, if $(\partial f_t/\partial x_{ft}) \neq 0$, the marginal value of food intake x_{ft} includes the additional term: $[(\partial U_t/\partial V_{t+1})(\partial W_{t+1}/\partial k_{t+1})\ (\partial f_t/\partial x_{ft})]/\lambda_t$. Second, if $(\partial g_t/\partial x_{ft}) \neq 0$, then the marginal cost of food intake includes the additional term $[-\partial g_t/\partial x_{ft}]$, showing that malnutrition affects the marginal cost of x_{ft}. When combined, these two effects influence the incentives to consume food x_{ft}. This reflects the fact that food intake now has two roles to play: its neoclassical role of generating utility, and its new role of maintaining productivity in situations of nutritional inadequacy. To illustrate, under severe food scarcity and hunger, we can expect $\partial f_t/\partial x_{ft} > 0$ (where better nutrition improves capital formation), and $\partial g_t/\partial x_{ft} > 0$ (where better nutrition improves labor productivity). This implies that, under hunger, the marginal cost of food would decrease while its marginal value would rise. Alternatively, under situations of obesity, we may have $\partial f_t/\partial x_{ft} < 0$ and $\partial g_t/\partial x_{ft} < 0$, with excessive food intake having adverse effects on both capital formation and labor productivity. It follows that, under obesity, the marginal cost of food would increase while its marginal value would decrease. The economic effects of malnutrition on consumption are further explored below.

4.2. Nutrition, consumption and investment under endogenous discounting

To explore how nutrition affects investment z_t, consider the first-order condition (9b). In (9b), the marginal value of investment is $(\partial U_t/\partial V_{t+1})(\partial W_{t+1}/\partial k_{t+1})/\lambda_t$, while the marginal cost is given by the price q_t. The marginal value is the discounted marginal value of future utility, involving both the discount factor $(\partial U_t/\partial V_{t+1})$ and the marginal utility of future capital $(\partial W_{t+1}/\partial k_{t+1})$. Applying the envelope theorem to (6) under differentiability, the marginal utility of capital is given by

$$\partial W_t/\partial k_t = (\partial U_t/\partial V_{t+1})(\partial W_{t+1}/\partial k_{t+1})(\partial f_t/\partial k_t) + \lambda_t\,(\partial g_t/\partial k_t). \quad (10)$$

This identifies two contributions: the discounted marginal utility of capital growth, $(\partial U_t/\partial V_{t+1})(\partial W_{t+1}/\partial k_{t+1})(\partial f_t/\partial k_t)$, and the marginal utility of income generated by capital, $\lambda_t\ (\partial g_t/\partial k_t)$. The first term reflects the role of capital accumulation in decisions. Substituting (10) into (9b) (after changing the t subscript) yields the following Euler equation

$$(\partial U_{t-1}/\partial V_t)\ [(\partial U_t/\partial V_{t+1})(\partial W_{t+1}/\partial k_{t+1})(\partial f_t/\partial k_t) + \lambda_t\ (\partial g_t/\partial k_t)] = \lambda_{t-1}\ q_{t-1}. \tag{9b'}$$

Equation (9b') characterizes optimal investment and capital accumulation. Under endogenous discounting and from Corollary 1, note that consumption x_t can influence the discount factor $(\partial U_t/\partial V_{t+1})$ in (9b'). This establishes new linkages between nutrition, consumption and investment. We will explore the behavioral implications of these linkages below.

To relate these results to previous literature, define <u>income</u> at time t as $I_t = g_t(k_t, x_{ft}) - q_t^T z_t$. In this context, income I_t is gross income from capital, $g_t(k_t, x_{ft})$, net of investment cost, $q_t^T z_t$. From the budget constraint, this is the amount of money available to be spent on consumption goods at time t. Then, from the optimization problem (6), the consumption decision (7) can be written <u>conditional on income I_t</u>. This gives

$$x_t^* = x_t^+(p_t, I_t^*, k_t), \tag{7'}$$

$$= x_t^+(p_t, g_t(k_t, x_{ft}^*) - q_t^T z_t^*, k_t) = x_t^*(p_t, q_t, k_t). \tag{7''}$$

where $I_t^* = g_t(k_t, x_{ft}^*(p_t, q_t, k_t)) - q_t^T z_t^*(p_t, q_t, k_t)$. Equations (7') and (7'') give alternative forms of optimal consumption behavior. While $x_t^*(p_t, q_t, k_t)$ in (7'') gives a reduced form representation of demand, equation (7') provides a more structural representation that isolates the effects of income I_t^*.

In equation (7'), the demand function $x_t^+(p_t, I_t^*, k_t)$ depends on price p_t, income I_t, and capital k_t. Specifying consumer demand as function of prices and income is standard in neoclassical consumer theory as well as in applied demand analysis (e.g., Deaton and Muellbauer). However, equation (7') exhibits two notable characteristics. First, it treats income I_t^* as an endogenous right-hand side variable (which depends on both capital income and investment cost). This suggests a need to control for income endogeneity in the empirical estimation of (7') (e.g., LaFrance; Dhar et al.). Second, after controlling for prices p_t and income I_t^*, equation (7') expresses consumer demand as a function of capital k_t. This effect is due to the recursive structure of preferences. To see that, consider the case of additive time preferences (3) where the discount factor $\partial U_t/\partial V_{t+1}$ is constant. Then, the marginal utility of investment in (9b), $(\partial U_t/\partial V_{t+1})(\partial W_{t+1}/\partial k_{t+1})$, no longer depends on the consumption goods x_t. In this situation, treating I_t^* as given, it follows that k_t no longer influences x_t^+, i.e. that $\partial x_t^+/\partial k_t = 0$ and $x_t^* = x_t^+(p_t, I_t^*)$. This means that, under additive time preferences, consumption decisions become <u>separable</u> from capital accumulation: capital accumulation can affect consumption only through its effects on income I_t^* (e.g., Singh et al.). Alternatively, finding evidence that capital k_t affects consumption decisions (where $\partial x_t^+/\partial k_t \neq 0$) is necessarily associated with non-additive time preferences. It means that under endogenous discounting (and after controlling for income I_t^*), consumption decisions are <u>not separable</u> from capital accumulation. Thus, examining whether capital k_t affects demand x_t^+ provides a simple test for the presence of endogenous discounting (where $\partial U_t/\partial V_{t+1}$ is not constant). Empirical investigations of the effects of capital on consumption behavior have been reported in the literature (e.g., West and Price). This is typically motivated treating capital as a "preference shifter". Our analysis suggests a different interpretation: finding evidence that capital affects demand x_t^+ implies that the discount factor is endogenous. In this case, besides its effects on income I_t^*, capital k_t also has a direct effect on demand x_t^+.

Finally, note that while $x_t^+(p_t, I_t^*, k_t)$ in (7') provides convenient linkages with standard neoclassical demands, it may be of limited usefulness in analyzing economic behavior. Indeed, some important aspects of consumer behavior are "hidden" in the effects of income. First, prices (p_t, q_t) and capital k_t affect income $I_t^* = g(k_t, x_t^*) - q_t^T z_t^*$ through the investment decision $z_t^*(p_t, q_t, k_t)$. Given the empirical prevalence of income effects, neglecting such effects can misrepresent how prices and capital affect microeconomic behavior. Second, in situations where malnutrition affects productivity, then x_t also affects gross income $g_t(k_t, x_t^*)$, with $\partial g_t/\partial x_{ft} \neq 0$. In this case, consumption behavior itself has a direct effect on income $I_t^* = g(k_t, x_t^*) - q_t^T z_t^*$. Then, $x_t^+(p_t, I_t^*, k_t)$ in equation (7') exhibits an even higher level of endogeneity: the variable x_t^* appears both as a left-hand side <u>and</u> a right-hand side variable. In this context, the neo-classical demand specification $x_t^+(p_t, I_t^*, k_t)$ does not seem to provide a useful representation of consumption behavior. This illustrates the importance of nutrition issues as well as the profound effects they can have in economic analysis.

5. Behavior under Risk

In this section, we further investigate the economics of consumption and investment behavior. Since the future is typically imperfectly known, we introduce risk in the analysis. For simplicity, we assume that there is a single capital good. We introduce risk by assuming that the future values of the state variable k are not known with certainty. In the state equation (1a), we consider $f_t(k_t, \cdot) = \overline{f}_t(k_t, \cdot) + \sigma_t e_t$, where e_t is a random variable with mean zero and variance 1, and σ_t is the standard deviation (or mean-preserving spread) of k_{t+1}.[8] Under risk, following Epstein and Hynes, we focus our attention on the case where the recursive preferences in (5) take the form

$$V_t(x_t, x_{t+1}, \ldots, x_T) = U_t(x_t) + r_t(x_t)\, E_t V_{t+1}(x_{t+1}, \ldots, x_T), \tag{5'}$$

where E_t is the expectation operator based on the subjective probability distribution of e_t, $V_{t+1}(x_{t+1}, \ldots, x_T) > 0$ is a von Neumann-Morgenstern utility function, and the discount factor is $r_t(x_t) = \partial V_t/\partial E_t V_{t+1}$ satisfying $0 \leq r_t(x_t) < 1$, $t = 1, \ldots, T$, with $V_{T+1} = 0$. Given Corollary 1, we assume that $r_t(x_t)$ is increasing in the food consumption bundle x_{ft} ($\partial r_t/\partial x_{ft} > 0$) for "low" x_{ft}, but decreasing in x_{ft} ($\partial r_t/\partial x_{ft} < 0$) for "high" x_{ft}. Without a loss of generality, we normalize prices such that the price of the capital good z_t is equal one: $q_t = 1$. Then, under non-satiation and assuming an interior solution, the budget constraint can be solved for z_t, implying that equation (6) can be written as

$$W_t(k_t) = \text{Max}_{x_t} \{U_t(x_t) + r_t(x_t)\, E_t W_{t+1}[f_t(k_t, x_t) + g_t(k_t, x_t) - p_t^T x_t]) : x_t \in X_t\}. \tag{6'}$$

In general, the shape of the utility function $W_{t+1}(k_{t+1})$ reflects risk preferences. Below, we will assume non-satiation in income ($\partial W_{t+1}/\partial k_{t+1} > 0$), risk aversion (corresponding to $\partial^2 W_{t+1}/\partial k_{t+1}^2 < 0$; see Pratt), and downside risk aversion (corresponding to $\partial^3 W_{t+1}/\partial k_{t+1}^3 > 0$; see Menezes et al.). As shown by Pratt, $\partial^3 W_{t+1}/\partial k_{t+1}^3 > 0$ is implied by decreasing absolute risk aversion (DARA), where DARA means that the Arrow-Pratt risk premium declines with wealth. Assuming $\partial^2 W_{t+1}/\partial k_{t+1}^2 < 0$ and $\partial^3 W_{t+1}/\partial k_{t+1}^3 > 0$ is motivated by the fact that both risk aversion and DARA (and thus aversion to downside risk) are basic characteristics of risk behavior for most individuals (e.g., Gollier).[9] Finally, note that equation (6') provides a separate characterization of risk aversion (as captured by the curvature of $W_{t+1}(\partial k_{t+1})$) and of intertemporal discounting (as captured by $r_t(x_t)$).

Let $g_t(k_t, x_t) = \mu_t + \overline{g}_t(k_t, x_t)$, where μ_t denotes exogenous income. And let $r_t(x_t) = s_t + \overline{r}_t(x_t)$, where s_t represents an exogenous shift in the discount factor, an increase in s_t being associated with a shift in preferences toward the future, i.e. with "higher patience." Then, the optimal consumption in (6') can be written as $x_t^*(\alpha_t)$, where $\alpha_t = (s_t, \mu_t, p_t, \sigma_t, k_t)$ is a vector of parameters representing the economic environment at time t. We want to investigate how changes in α_t affect behavior.

Under differentiability, the first-order conditions for an interior solution in (6') are

$$F_t \equiv \partial U_t/\partial x_t + (\partial r_t/\partial x_t)\, E_t W_{t+1}$$
$$+ r_t(x_t)\,(\partial f_t/\partial x_t + \partial g_t/\partial x_t - p_t^T)\, E_t(\partial W_{t+1}/\partial k_{t+1}) = 0. \tag{11}$$

Assume that the second-order sufficiency condition holds: $H_t \equiv \partial F_t/\partial x_t$ is a $(n\times n)$ symmetric negative-definite matrix. For a given α_t, applying the implicit function theorem to (11) evaluated at x_t^* yields the comparative statics result

$$\partial x_t^*/\partial \alpha_t = -H_t^{-1}\, \partial F_t/\partial \alpha_t, \tag{12a}$$

expressing how a small change in α_t affects optimal consumption x_t^*.

To obtain information on investment behavior, the budget constraint under non-satiation implies that $z_t^* = g_t(k_t, x_t^*) - p_t^T\, x_t^*$. Under differentiability, it follows that the marginal effect of α_t on investment z_t^* is

$$\partial z_t^*/\partial \alpha_t = \partial g_t/\partial \alpha_t - (p_t^T - \partial g_t/\partial x_t)(\partial x_t^*/\partial \alpha_t). \tag{12b}$$

Finally, the impact of α_t on capital growth is obtained from the state equation evaluated at the optimum: $k_{t+1}^* = f_t(k_t, x_t^*) + z_t^*$. It implies that

$$\partial k_{t+1}^*/\partial \alpha_t = \partial f_t/\partial \alpha_t + \partial g_t/\partial \alpha_t - (p_t^T - \partial f_t/\partial x_t - \partial g_t/\partial x_t)(\partial x_t^*/\partial \alpha_t). \tag{12c}$$

5.1. The effects of patience

Consider the situation where $r_t(x_t) = s_t + \overline{r_t}(x_t)$, a rise in the parameter s_t representing an increase in patience. From equations (11) and (12), we obtain

$$\partial x_t^*/\partial s_t = H_t^{-1} (p_t^T - \partial f_t/\partial x_t - \partial g_t/\partial x_t)^T E_t(\partial W_{t+1}/\partial k_{t+1}), \tag{13a}$$

$$\partial z_t^*/\partial s_t = -(p_t^T - \partial g_t/\partial x_t) H_t^{-1} (p_t^T - \partial f_t/\partial x_t - \partial g_t/\partial x_t)^T E_t(\partial W_{t+1}/\partial k_{t+1}), \tag{13b}$$

$$\partial k_{t+1}^*/\partial s_t = -(p_t^T - \partial f_t/\partial x_t - \partial g_t/\partial x_t) H_t^{-1} (p_t^T - \partial f_t/\partial x_t - \partial g_t/\partial x_t)^T E_t(\partial W_{t+1}/\partial k_{t+1}) \geq 0. \tag{13c}$$

Given $\partial W_{t+1}/\partial k_{t+1} > 0$ and the negative definiteness of H_t^{-1}, equation (13a) implies that $(p_t^T - \partial f_t/\partial x_t - \partial g_t/\partial x_t)(\partial x_t^*/\partial s_t) \leq 0$. When $(p_t^T - \partial f_t/\partial x_t - \partial g_t/\partial x_t) \geq 0$ (i.e. when consumer prices p_t^T are at least as large as the marginal effects of consumption on household productivity, $\partial f_t/\partial x_t + \partial g_t/\partial x_t$), this means that the weighted sum of the comparative statics slopes $\partial x_t^*/\partial s_t$ is non-positive. In other words, an increase in patience s_t tends to have a negative effect on consumption x_t^*.

Given $\partial W_{t+1}/\partial k_{t+1} > 0$ and the negative definiteness of H_t^{-1}, equation (13b) implies that $\partial z_t^*/\partial s_t \geq -(\partial f_t/\partial x_t)(\partial x_t^*/\partial s_t)$. First, it follows that $\partial z_t^*/\partial s_t \geq 0$ when $\partial f_t/\partial x_t = 0$. In other words, when consumption does not affect capital growth ($\partial f_t/\partial x_t = 0$), an increase in patience always stimulates investment. From Corollary 1, this can be expected to apply to individuals facing adequate nutrition. Second, $\partial z_t^*/\partial s_t \geq -(\partial f_t/\partial x_t)(\partial x_t^*/\partial s_t)$ implies that $\partial z_t^*/\partial s_t \geq 0$ if $(\partial f_t/\partial x_t) \geq 0$ and $(\partial x_t^*/\partial s_t) \leq 0$. Thus, sufficient conditions for patience to stimulate investment are that consumption has a non-negative effect on capital accumulation ($\partial f_t/\partial x_t \geq 0$), and that patience has a non-positive effect on consumption ($\partial x_t^*/\partial s_t \leq 0$). As discussed above, the conditions $\partial f_t/\partial x_t \geq 0$ and $\partial f_t/\partial x_{ft} > 0$ may be found under severe hunger (where better nutrition stimulates the accumulation of human capital). However, these conditions may not hold in situations of extreme obesity (if excessive food consumption has adverse effects on capital accumulation: $\partial f_t/\partial x_{ft} < 0$). This indicates that the positive linkages between patience and investment incentives may become weaker under extreme obesity.

Given $\partial W_{t+1}/\partial k_{t+1} > 0$ and the negative-definiteness of H_t^{-1}, equation (13c) implies that $\partial k_{t+1}^*/\partial s_t \geq 0$. It establishes that an <u>increase in patience always stimulates capital formation</u>. This result is quite general (e.g., Hertzendorf). Importantly, it does <u>not</u> depend on the nutritional status of the individual. Intuitively, increasing patience means that the future becomes relatively more important, thus providing an incentive to accumulate capital.

These results show that patience has important effects on economic behavior. Under endogenous discounting, they suggest the need to isolate the effects of changing patience on behavior. This can be done by decomposing (12a) as follows

$$\partial x_t^*/\partial \alpha_t = \partial x_t^a/\partial \alpha_t + \partial x_t^b/\partial \alpha_t, \tag{12a'}$$

where $\partial x_t^a/\partial \alpha_t = -H_t^{-1}\, \partial[(\partial r_t/\partial x_t)\, E_t W_{t+1}]/\partial \alpha_t$ and $\partial x_t^b/\partial \alpha_t = -H_t^{-1}\, \partial[\partial U_t/\partial x_t + r_t(x_t)\, (\partial f_t/\partial x_t + \partial g_t/\partial x_t - p_t^T)\, E_t(\partial W_{t+1}/\partial k_{t+1})]/\partial \alpha_t$. Equation (12a') decomposes the effects of α_t on x_t^* into two additive terms. The first term $\partial x_t^a/\partial \alpha_t$ captures the effects of changing x_t on the discount factor $(\partial r_t/\partial x_t)$. It vanishes under exogenous discounting (when $\partial r_t/\partial x_t = 0$). Thus, it reflects endogenous discounting. The second term $\partial x_t^b/\partial \alpha_t$ captures all other effects: it measures the classical impact of α_t that would be obtained while neglecting $\partial r_t/\partial x_t$. Below, we will make extensive use of the decomposition given in (12a').

5.2. Income effects

Consider a change in exogenous income μ_t. From equations (11) and (12), we obtain the following results.

$$\partial x_t^*/\partial \mu_t = \partial x_t^a/\partial \mu_t + \partial x_t^b/\partial \mu_t, \tag{14a}$$

where $\partial x_t^a/\partial \mu_t = -H_t^{-1}\, (\partial r_t/\partial x_t)^T\, E_t(\partial W_{t+1}/\partial k_{t+1})$, and $\partial x_t^b/\partial \mu_t = H_t^{-1}\, (p_t^T - \partial f_t/\partial x_t - \partial g_t/\partial x_t)^T\, r_t(x_t)\, E_t(\partial^2 W_{t+1}/\partial k_{t+1}^2)$,

$$\partial z_t^*/\partial \mu_t = 1 - (p_t^T - \partial g_t/\partial x_t)(\partial x_t^*/\partial \mu_t), \tag{14b}$$

$$\partial k_{t+1}^*/\partial \mu_t = 1 - (p_t^T - \partial f_t/\partial x_t - \partial g_t/\partial x_t)(\partial x_t^*/\partial \mu_t). \tag{14c}$$

Equation (14a) decomposes the effect of income μ_t on consumption x_t^* into two additive parts: $\partial x_t^a/\partial\mu_t$ and $\partial x_t^b/\partial\mu_t$. The first term $\partial x_t^a/\partial\mu_t$ reflects endogenous discounting. In addition, given $\partial W_{t+1}/\partial k_{t+1} > 0$ and the negative definiteness of H_t^{-1}, it satisfies $(\partial r_t/\partial x_t)\ (\partial x_t^a/\partial\mu_t) \geq 0$. Thus, when $\partial r_t/\partial x_t \geq 0$ (≤ 0), a weighted sum of the terms in $(\partial x_t^a/\partial\mu_t)$ tends to be positive (negative). This implies that endogenous discounting tends to strengthen (weaken) the income effect $\partial x_t^*/\partial\mu_t$ when $\partial r_t/\partial x_t \geq 0$ (≤ 0). From Corollary 1, this suggests that situations of severe hunger would contribute to stronger income effects $\partial x_t^*/\partial\mu_t$, while situations of severe obesity would contribute to weaker income effects $\partial x_t^*/\partial\mu_t$. By identifying the role of nutrition, this generates new and useful information on the factors affecting the classical Engel curve relating consumption to income. For example, Zeldes, and Carroll and Kimball have shown that uncertainty contributes to the concavity of the Engel curve. To the extent that hunger is associated with very low income and obesity with higher income, our analysis indicates that nutritional considerations also contribute to the concavity of the Engel curve.

The second term $\partial x_t^b/\partial\mu_t$ in (14a) is proportional to $\partial^2 W_{t+1}/\partial k_{t+1}^2$. Under risk aversion, $\partial^2 W_{t+1}/\partial k_{t+1}^2 < 0$, implying that $(p_t^T - \partial f_t/\partial x_t - \partial g_t/\partial x_t)\ (\partial x_t^b/\partial\mu_t) \geq 0$. In the case where $(p_t^T - \partial f_t/\partial x_t - \partial g_t/\partial x_t) \geq 0$ (i.e., where consumer prices p_t are at least as large as the marginal impact of consumption on productivity, $\partial f_t/\partial x_t + \partial g_t/\partial x_t$), this implies that a weighted sum of the terms in $(\partial x_t^b/\partial\mu_t)$ is positive. It means that risk aversion contributes to a positive effect of income on consumption.

Equation (14b) follows from (12b). Given $q_t = 1$, it evaluates the marginal propensity to invest, $\partial z_t^*/\partial\mu_t$. The marginal propensity to spend is $(p_t^T - \partial g_t/\partial x_t)(\partial x_t^*/\partial\mu_t)$, where consumer prices p_t are adjusted by the marginal impact of consumption on household income $\partial g_t/\partial x_t$. Then, from equation (12b), the marginal propensity to invest $\partial z_t^*/\partial\mu_t$ is 1 minus the marginal propensity to spend. In the case where $\partial x_t^*/\partial\mu_t \geq 0$, this implies that $\partial z_t^*/\partial\mu_t \leq 1$ if $(p_t^T - \partial g_t/\partial x_t) \geq 0$. Under such a scenario, the marginal propensity to invest is less than 1. This means that part of the additional income due to a rise in μ_t is spent on consumption goods. In situations where endogenous discounting satisfies $\partial r_t/\partial x_t \geq 0$ (e.g., hunger), we have seen that it would strengthen $\partial x_t^*/\partial\mu_t$. Assuming $(p_t^T - \partial g_t/\partial x_t) \geq 0$ and from (14b), this means that under hunger, endogenous discounting would weaken $\partial z_t^*/\partial\mu_t$, i.e. reduce the incentive to invest. Alternatively, when endogenous discounting satisfies $\partial r_t/\partial x_t \leq 0$ (e.g., under obesity), it would strengthen $\partial z_t^*/\partial\mu_t$, i.e. stimulate investment.

Finally, equation (14c) is obtained from (12c). In a way similar to (14b), it implies that $\partial k_{t+1}^*/\partial\mu_t \leq 1$ if $(p_t^T - \partial f_t/\partial x_t - \partial g_t/\partial x_t) \geq 0$ and $\partial x_t^*/\partial\mu_t \geq 0$. If endogenous discounting strengthens $\partial x_t^*/\partial\mu_t$ (when $\partial r_t/\partial x_t \geq 0$), this means that it would also contribute to reducing capital formation. In other words, from Corollary 1, situations of hunger would be associated with limited accumulation of capital. The policy implications of this result will be explored below. Alternatively, $\partial r_t/\partial x_t \leq 0$ (e.g., situations of obesity) would weaken $\partial x_t^*/\partial\mu_t$ and imply that endogenous discounting stimulates capital formation.

5.3. Price effects

Using equations (12) and (14a), the impact of changing consumer prices p_t gives the following results.

$$\partial x_t^*/\partial p_t = \partial x_t^c/\partial p_t - (\partial x_t^*/\partial\mu_t)\, x_t^{*T}, \tag{15a}$$

where $\partial x_t^c/\partial p_t \equiv H_t^{-1}\, r_t(x_t)\, E_t(\partial W_{t+1}/\partial k_{t+1})$,

$$\partial z_t^*/\partial p_t = -(p_t^T - \partial g_t/\partial x_t)(\partial x_t^*/\partial p_t), \tag{15b}$$

$$\partial k_{t+1}^*/\partial p_t = -(p_t^T - \partial f_t/\partial x_t - \partial g_t/\partial x_t)(\partial x_t^*/\partial p_t). \tag{15c}$$

Equation (15a) provides the standard Slutsky decomposition of Marshallian price effects, $\partial x_t^*/\partial p_t$, into substitution effects (represented by Hicksian price effects: $\partial x_t^c/\partial p_t \equiv H_t^{-1}\, r_t(x_t)\, E_t(\partial W_{t+1}/\partial k_{t+1})$), plus income effects: $-(\partial x_t^*/\partial\mu_t)\, x_t^{*T}$. Given $\partial W_{t+1}/\partial k_{t+1} > 0$ and the symmetry negative-definiteness of H_t^{-1}, the $(n\times n)$ matrix $\partial x_t^c/\partial p_t$ is symmetric, negative-definite. Then equation (15a) yields the standard integrability conditions: the $(n\times n)$ Slutsky matrix $[\partial x_t^*/\partial p_t + (\partial x_t^*/\partial\mu_t)\, x_t^{*T}]$ is symmetric, negative-definite. From Corollary 1, we associated malnutrition with a small discount factor $r_t(x_t)$. This suggests that malnutrition tends to reduce the magnitude of Hicksian price effects $|\partial x_t^c/\partial p_t|$, i.e. to make Hicksian demands more price inelastic. In addition, we have seen that endogenous discounting tends to strengthen (weaken) income effects $\partial x_t^*/\partial\mu_t$ when $\partial r_t/\partial x_t \geq 0$ (≤ 0). From Corollary 1 and equation (15a), this means that obesity (where $\partial r_t/\partial x_{ft} \leq 0$) would contribute to more inelastic price response of Marshallian demands. This illustrates how nutrition can affect the price elasticity of consumer demand. Finally, equations (15b) and (15c) follow from (12b) and (12c). They imply that the effects of prices p_t on investment and capital accumulation are expected to be small in situations of obesity.

5.4. Risk effects

Uncertainty in future values of the state variable k is captured by the mean-preserving spread parameter σ_t, where $f_t(k_t, \cdot) = \overline{f}_t(k_t, \cdot) + \sigma_t\, e_t$, e_t being a random variable with mean zero and variance 1. Using equations (12), evaluating the impact of changing the mean-preserving spread parameter σ_t gives the following results:

$$\partial x_t^*/\partial\sigma_t = \partial x_t^a/\partial\sigma_t + \partial x_t^b/\partial\sigma_t, \tag{16a}$$

where $\partial x_t^a/\partial\sigma_t = -H_t^{-1}\,[(\partial r_t/\partial x_t)^T\, E_t[(\partial W_{t+1}/\partial k_{t+1})\, e_{t+1}]$, and $\partial x_t^b/\partial\sigma_t = H_t^{-1}\,[r_t(x_t)\,(p_t^T - \partial f_{t+1}/\partial x_t - \partial g_t/\partial x_t)^T$ $E_t[(\partial^2 W_{t+1}/\partial k_{t+1}^2)\, e_{t+1}]]$,

$$z_t^*/\partial\sigma_t = -(p_t^T - \partial g_t/\partial x_t)(\partial x_t^*/\partial\sigma_t), \tag{16b}$$

$$\partial k_{t+1}^*/\partial\sigma_t = -(p_t^T - \partial f_{t+1}/\partial x_t - \partial g_t/\partial x_t)(\partial x_t^*/\partial\sigma_t). \tag{16c}$$

Equation (16a) decomposes the effect of a change in σ_t into two additive terms: $\partial x_t^a/\partial\sigma_t$ and $\partial x_t^b/\partial\sigma_t$. The first term $\partial x_t^a/\partial\sigma_t$ reflects endogenous discounting. Indeed, it vanishes under exogenous discounting and time-additive preferences (where $\partial r_t/\partial x_t = 0$). In addition, note that $E_t[(\partial W_{t+1}/\partial k_{t+1})\, \varepsilon_{t+1}] = Cov_t(\partial W_{t+1}/\partial k_{t+1}, e_{t+1}) = sign(\partial^2 W_{t+1}/\partial k_{t+1}^2) < 0$ under risk aversion. Given that H_t^{-1} is negative definite, it follows that under risk aversion, $\partial x_t^a/\partial\sigma_t$ satisfies $(\partial r_t/\partial x_t)\,(\partial x_t^a/\partial\sigma_t) \leq 0$. Corollary 1 indicates that $\partial r_t/\partial x_{ft} \geq 0$ under hunger, but $\partial r_t/\partial x_{ft} \leq 0$ in situations of obesity. Thus, under risk aversion, a weighted sum of the terms in $\partial x_t^a/\partial\sigma_t$ would tend to be negative in situations of hunger, but positive under obesity. This shows how the effects of risk can vary across individuals depending on their nutritional status.

The second term $\partial x_t^b/\partial\sigma_t$ in (16a) is proportional to $E_t[(\partial^2 W_{t+1}/\partial k_{t+1}^2)\, e_{t+1}]$. Note that $E_t[(\partial^2 W_{t+1}/\partial k_{t+1}^2)\, e_{t+1}] = Cov_t(\partial^2 W_{t+1}/\partial k_{t+1}^2, e_{t+1}) = sign(\partial^3 W_{t+1}/\partial k_{t+1}^3) > 0$ under downside risk aversion. Thus, under downside risk aversion, the following relationship holds in general: $(p_t^T - \partial f_{t+1}/\partial x_t - \partial g_t/\partial x_t)$ $(\partial x_t^b/\partial\sigma_t) \leq 0$. When $(p_t^T - \partial f_{t+1}/\partial x_t - \partial g_t/\partial x_t) \geq 0$, this means that a weighted sum of the terms in $\partial x_t^b/\partial\sigma_t$ tends to be negative (with $(p_t^T - \partial f_{t+1}/\partial x_t - \partial g_t/\partial x_t)$ as weights).

Thus, for non-obese individuals who are risk averse as well as downside risk averse, an increase in risk σ_t would tend to decrease consumption x_t^*. Alternatively, for obese individuals satisfying Corollary 1, the net effect of risk on consumption is indeterminate: it depends on the relative magnitude of the two terms $\partial x_t^a/\partial\sigma_t$ and $\partial x_t^b/\partial\sigma_t$ in (16a). This implies that endogenous discounting and risk interact in their effects on consumption behavior. By showing how malnutrition influences risk effects, it documents how nutritional status can contribute to heterogeneity in risk behavior across individuals.

Equation (16b) and (16c) follows from (12b) and (12b). Note that Kimball defined "prudence" as any situation where increased future risk tends to stimulate saving/investment. Thus, prudence corresponds to $\partial z_t^*/\partial\sigma_t \geq 0$. From (16b), it follows that the household is prudent if and only if $(p_t^T - \partial g_t/\partial x_t)(\partial x_t^*/\partial\sigma_t) \leq 0$. When $(p_t^T - \partial g_t/\partial x_t) \geq 0$, a sufficient condition for prudence is that $\partial x_t^*/\partial\sigma_t \leq 0$. Situations under which $\partial x_t^*/\partial\sigma_t \leq 0$ may hold were just discussed. As noted above, risk aversion (where $\partial^2 W_{t+1}/\partial k_{t+1}^2 < 0$), downside-risk aversion (where $\partial^3 W_{t+1}/\partial k_{t+1}^3 > 0$) and endogenous discounting contribute to a negative impact of risk σ_t on consumption x_t^* for non-obese individuals. In this context, having $\partial^3 W_{t+1}/\partial k_{t+1}^3 > 0$ is neither necessary nor sufficient to generate prudent behavior (see Hau).

Similar results are obtained from equation (16b). It shows that sufficient conditions for risk σ_t to stimulate capital formation $(\partial k_{t+1}^*/\partial\sigma_t \geq 0)$ are that $(p_t^T - \partial f_{t+1}/\partial x_t - \partial g_t/\partial x_t) \geq 0$ and $\partial x_t^*/\partial\sigma_t \leq 0$. Under such conditions, higher risk σ_t tends to make the household more prudent, thus reducing current consumption expenditures and stimulating investment and capital accumulation. However, we found that it is possible to have $\partial x_t^*/\partial\sigma_t \geq 0$ under situations of obesity (i.e., when $\partial x_t^a/\partial\sigma_t$ is positive and sufficiently large). Under such a scenario, higher risk would stimulate consumption and reduce investment and capital formation. Again, this shows how endogenous discounting can affect risk behavior.

5.5. Capital effects

Using equations (12), the impact of a change in initial capital k_t is given by

$$\partial x_t^*/\partial k_t = \partial x_t^a/\partial k_t + \partial x_t^a/\partial k_t, \tag{17a}$$

where $\partial x_t^a/\partial k_t = -H_t^{-1} [(\partial r_t/\partial x_t)^T E_t(\partial W_{t+1}/\partial k_{t+1})(\partial f_t/\partial k_t + \partial g_t/\partial k_t)]$, and $\partial x_t^b/\partial k_t = -H_t^{-1} [r_t(x_t) E_t(\partial^2 W_{t+1}/\partial k_{t+1}^2)(\partial f_t/\partial k_t + \partial g_t/\partial k_t)(\partial f_t/\partial x_t + \partial g_t/\partial x_t - p_t^T)^T + E_t(\partial W_{t+1}/\partial k_{t+1})(\partial^2 f_t/\partial x_t\partial k_t + \partial^2 g_t/\partial x_t\partial k_t)]$,

$$\partial z_t^*/\partial k_t = \partial g_t/\partial k_t - (p_t^T - \partial g_t/\partial x_t)(\partial x_t^*/\partial k_t), \tag{17b}$$

$$\partial k_{t+1}^*/\partial k_t = \partial f_t/\partial k_t + \partial g_t/\partial k_t - (p_t^T - \partial f_t/\partial x_t - \partial g_t/\partial x_t)(\partial x_t^*/\partial k_t). \tag{17c}$$

Equation (17a) decomposes the effect of capital k_t on consumption x_t^* into two terms. The first term $\partial x_t^a/\partial k_t$ vanishes under exogenous discounting (where $\partial r_t/\partial x_t = 0$). Thus, it represents the effect of endogenous discounting. In the case where $(\partial f_t/\partial k_t + \partial g_t/\partial k_t) \geq 0$, it satisfies $(\partial r_t/\partial x_t)\ (\partial x_t^a/\partial k_t) \geq 0$, implying that $(\partial x_t^a/\partial k_t)$ tends to be positive (negative) when $\partial r_t/\partial x_t \geq 0$ (≤ 0). From Corollary 1, this means that endogenous discounting tends to stimulate (reduce) the effects of capital on consumption in situations of hunger (obesity).

The second term in (17a) $\partial x_t^b/\partial k_t$ captures the effects of risk aversion (as represented by $\partial^2 W_{t+1}/\partial k_{t+1}^2$) as well as the impact of x_t on productivity. First, consider the case of an adequate diet where consumption has no effect on productivity (with $\partial f_t/\partial x_t = 0$ and $\partial g_t/\partial x_t = 0$). Then the second term in (17a) reduces to $\partial x_t^b/\partial k_t = H_t^{-1}\ p_t\ r_t(x_t)\ E_t(\partial^2 W_{t+1}/\partial k_{t+1}^2)(\partial f_t/\partial k_t + \partial g_t/\partial k_t)$. Under risk aversion (where $\partial^2 W_{t+1}/\partial k_{t+1}^2 < 0$), this implies that $(\partial f_t/\partial k_t + \partial g_t/\partial k_t)\ p_t^T\ (\partial x_t^b/\partial k_t) \geq 0$, i.e. that $\partial x_t^b/\partial k_t$ tends to be positive when $(\partial f_t/\partial k_t + \partial g_t/\partial k_t) \geq 0$. From Corollary 1, adequate nutrition also corresponds to $\partial r_t/\partial x_t \approx 0$. From (17a), this would imply that for a well-nourished risk averse individual, $\partial x_t^*/\partial k_t$ is expected to be positive, with consumption rising with an increase in capital. Second, consider the case of malnutrition where consumption influences household productivity (with $\partial f_t/\partial x_t \neq 0$ and/or $\partial g_t/\partial x_t \neq 0$). Then, from (17a), these productivity effects would affect $\partial x_t^b/\partial k_t$ and thus $\partial x_t^*/\partial k_t$. This indicates that, under malnutrition, the impact of initial capital k_t on consumption x_t^* become more complex. Yet, from (17a), in the case where hunger is associated with food x_{ft} having a positive effect on productivity and on the marginal productivity of capital, we still expect $\partial x_t^*/\partial k_t$ to be positive for a risk averse individual facing hunger.

Equations (17b) and (17c) follow from (12b) and (12c). In situations where $(p_t^T - \partial g_t/\partial x_t) \geq 0$, equation (17b) implies that $\partial z_t^*/\partial k_t \leq (\geq)\ \partial g_t/\partial k_t$ if $\partial x_t^*/\partial k_t \geq (\leq)\ 0$. And in situations where $(p_t^T - \partial f_t/\partial x_t - \partial g_t/\partial x_t) \geq 0$, equation (17c) implies that $\partial k_{t+1}^*/\partial k_t \leq (\geq)\ \partial f_t/\partial k_t + \partial g_t/\partial k_t$ if $\partial x_t^*/\partial k_t \geq (\leq)\ 0$. As discussed above and using corollary 1, under adequate nutrition and risk aversion, we expect $\partial x_t^*/\partial k_t$ to be positive. Under such a scenario, a higher initial capital would contribute to decreasing $\partial k_{t+1}^*/\partial k_t$, i.e. dampening capital accumulation. In addition, we have seen that, under endogenous discounting, hunger is expected to strengthen the positive effect of capital on consumption $\partial x_t^*/\partial k_t$. This means that, under situations of hunger, endogenous discounting would contribute to weakening the effect of initial capital k_t on investment z_t^* and capital accumulation k_{t+1}^*. We argue below that this weakening effect has important policy implications.

6. Some Policy Implications

What are the implications of endogenous discounting? As just argued, it strengthens the linkages between consumption and investment decisions. First, from the budget constraint, gross income is allocated between consumption and investment. As a result, for a given income, there is always a trade-off between these two activities (e.g., buying more consumer goods always means less money spent on investment). And this effect is present irrespective of the structure of preferences. Second, endogenous discounting generates an additional effect: choosing a consumption bundle x_t that affects the discount factor $\partial U_t/\partial V_{t+1}$ also influences how the individual views the future and thus its incentives to invest. On this issue, equation (13c) shows that an increase in patience always stimulates capital formation: $\partial k_{t+1}^*/\partial s_t \geq 0$. This is intuitive: a rise in the discount factor implies an increase in the relative importance of the future, and thus an increase in the incentive to invest. What is new here is that current consumption goods x_t (and in particular food intake x_{ft}, as stated in Corollary 1) are specified as factors affecting the discount factor $\partial U_t/\partial V_{t+1}$. This establishes new relationships between nutrition, consumption and capital growth. Since formations of both physical and human capital are the basic engines of economic growth (e.g. Barro, 1990, 1996; Chavas; Dolmas; Jones and Manuelli; Lucas; Mankiw et al.; Rebelo; Romer), this provides interesting linkages between nutrition, economic behavior and economic growth. Below, we explore the economic and policy implications of these linkages in the context of Corollary 1.

First, consider situations of poverty and hunger. Starting from low levels of x_f, increasing food intake tends to increase patience (from Corollary 1), which would stimulate investment in physical and human capital. Alternatively, lowering food consumption x_{ft} decrease $\partial U_t/\partial V_{t+1}$, dampens investment in physical and human capital, and deters long term economic growth. To the extent that capital accumulation is crucial in generating economic growth, this establishes a strong linkage between food consumption and economic growth. It provides new insights into the health-related determinants of economic development (e.g., Arcand; Fogel; Sachs, 2001; Sachs and Warner; Wang and Tanigushi). In particular, it shows how malnutrition can deter long term economic growth.

This result provides useful insights into the existence of poverty trap. To illustrate, consider the case of a very poor individual. Because of a low income, he/she faces food insecurity and malnutrition. From Corollary 1, his/her low food consumption means that he/she discounts the future heavily. This implies a focus on short term survival and little incentive to invest. This is reflected in equations (17b) and (17c), which were used to show that, under hunger, endogenous discounting contributes to weakening investment. With limited investment, the individual has poor prospects for capital accumulation. And without capital accumulation, his/her income stream cannot grow over time. As a result, poor individuals cannot find a way out of poverty. In this case, the poverty trap is induced in part by endogenous discounting under Corollary 1.[10] Indeed, without endogenous discounting, the adverse effects of poverty and hunger on investment incentives would be weaker.

This has implications for the effects of transfers and income redistribution policies. For example, consider a transfer toward a poor individual facing food insecurity. If this transfer increases current food consumption, it also increases patience (from Corollary 1) and stimulates investment. In the case where investment contributes to significant capital accumulation, then it can put the individual on a path to income growth. Thus, in principle, a transfer toward the poor can get them out of the poverty trap and toward economic growth. Importantly, note that the transfer does not need to be permanent. Indeed, if a temporary transfer to a poor individual gets him/her out of the poverty trap, then income may get on a path of endogenous growth once out of the poverty trap.

These arguments suggest that transfers toward the poor can be an effective part of economic policy. This effectiveness depends in part on the ability to improve the nutritional status of the poor. Indeed, from Corollary 1, improving nutrition increases the incentive to invest. However, there are scenarios where income transfers can fail to stimulate investment and income growth. First, this can occur if income transfers are spent mostly on non-food consumption. From equations (14), spending the income transfer mostly on non-food items may mean little effect on discounting, on investment incentive and on capital formation. To the extent that stimulating economic growth is an important policy objective, this stresses the importance of targeting the beneficiaries of income transfers. Second, even if transfers targeting the poor can improve their welfare in the short run, this may fail to get them out of poverty in the long term. This would depend on the existing opportunities for capital accumulation. The prospects for accumulating either physical or human capital can be poor if the economic environment is unfavorable (e.g., lack of infrastructure, badly functioning markets, credit rationing, high scarcity level, absence of technological progress) and/or human capital is inadequate (e.g., low education, inferior managerial abilities, physical handicap). Under such circumstances, the opportunities for income growth may be quite limited. This indicates that the economic efficacy of transfers can depend greatly on the existing levels of human capital and infrastructure. Conditions favorable to capital accumulation (e.g., some minimal level of human capital and infrastructure and properly functioning markets) are required for transfers to stimulate economic growth.

Note that these arguments are broadly applicable. They apply to transfers taking place at all levels of analysis: at the local level, the regional level, the national level, as well as the international level. As such, they provide useful insights into redistribution policies for local communities, national government as well as international aid. By providing linkages between redistribution and economic growth, they can be used in positive analysis as well as normative analysis. For example, they may help refine the design of redistribution policies to improve their effects on long term income growth.

Next, consider situations of obesity. Such situations arise when individuals make food consumption decisions while heavily discounting the future heath benefits of a more balanced diet. One policy option would be to tax selected high-calorie food items in an attempt to decrease their consumption, thus reducing calorie intake. Our analysis provides some information on this option. We showed that obesity tends to contribute to the price inelasticity of consumer demand. This means that imposing taxes on high-calorie food items may have only a small effect on food consumption. In other words, taxing the foods that are thought to contribute to the obesity epidemic may not be very effective in reducing the obesity rate. In addition, there is typically much heterogeneity in obesity among individuals within any socio-demographic group. This means that taxing specific food items would not provide precise targeting of obese individuals. For many individuals, obesity problems are often developing over many years, reflecting slow-moving dynamics underlying nutrition and health. This indicates that policies focusing on early interventions and prevention could be particularly effective against the obesity epidemic. This includes improved nutrition education for infants and children.

Finally, our analysis provides new insights into factors contributing to heterogeneous behavior across individuals. For example, in the analysis of consumption behavior, we showed that hunger would contribute to stronger income effects, while severe obesity would weaken income effects. This indicates that economic behavior (including both consumption and investment behavior) may change significantly across the income spectrum and would depend on the nutritional status of individuals. We also showed that the negative effect of risk on consumption and its positive effect on investment would be stronger under hunger. This suggests new directions of inquiry into positive economic analysis of how nutrition, risk and the distribution of income can affect consumption and investment behavior.

7. Concluding Remarks

We have explored the linkages between food demand, nutrition, investment and capital formation. A key aspect of the arguments relates to how malnutrition can have adverse effects on investment incentives. These effects are captured in the context of non-additive preferences where the discount factor (reflecting time preferences) is endogenous and depends on food intake. This gives useful insights on how food consumption affects investment incentives and capital accumulation. While the standard time additive model may be appropriate for well-nourished individuals, it appears inappropriate in situations of malnutrition (involving either nutrient deficiencies or obesity). Under malnutrition, we explored the implications of endogenous discounting for consumption and investment behavior. In this context, we identified the effects of income, prices, risk and initial capital on consumption and investment behavior. We investigated how economic behavior can vary with the nutritional status of individuals. And we briefly explored the implications of our results for economic policy. For example, we found that hunger can strengthen the positive effects of income on consumption, thus weakening the incentive to invest. As a result, hunger can contribute to a poverty trap, where prospects for capital accumulation and economic growth are poor. We also found that obesity contributes to the price inelasticity of consumer demand. This reduces the effectiveness that a tax on high-calorie food would have as a means to combat the obesity epidemic.

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Footnotes

[1] Note that we will introduce risk in the analysis in section 5 below. In this context, Carroll has argued that the presence of liquidity constraints generates behavior that is virtually indistinguishable from precautionary behavior under uncertainty.

[2] Note that a difference equation of any (finite) order can always be expressed as a first-order difference of equation by an appropriate increase in the number of state variables. In this context, equation (1a) provides a general representation of dynamics in the state variables y_t.

[3] In general, leisure would be included in x_t, with the wage rate as its opportunity cost (e.g., see Deaton and Muellbauer, chapter 4).

[4] Note that since z_t can be negative, the investment cost (q_t z_t) can also be negative. If so, ($-q_t$ z_t) would reflect the monetary value of capital liquidation and/or borrowing.

[5] Equation (3) assumes that preferences are time additive. Although this may appear restrictive, note that all arguments presented below would remain valid if equation (3) were to take a non-additive form.

[6] However, note that some non-food items also contribute to health (e.g., medical services). Such consumption goods can be expected to behave in a way similar to food intake and would likely satisfy Corollary 1 as well. Then, the analysis presented below would apply in this broader context.

[7] When $T \rightarrow \infty$ and under stationarity, the existence of a steady state solution to (3) is discussed by Boyd.

[8] Note that future price uncertainty could be introduced in the model by including prices among the state variables. However, this would require relaxing the assumption of single capital good.

[9] Also note that, under time additive preferences, Kimball has associated $\partial^3 W_{t+1}/\partial k_{t+1}{}^3 > 0$ with "prudence".

[10] Note that this effect (and thus the existence of a poverty trap) would be strengthened if, in addition, malnutrition decreases household productivity (as discussed above). And it may be strengthened further in the presence of credit rationing. However, as noted by Carroll, distinguishing between the effects of liquidity constraints and precautionary behavior under uncertainty may prove difficult.