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Does Better Nutrition Cause Economic Growth?
The Efficiency Cost of Hunger Revisited

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Abstract

This paper considers the impact of the nutritional status on the growth rate of real GDP per capita. In particular, a panel of 114 countries' Dietary Energy Supply (DES) per capita from 1961 to 1999 is combined with the latest release of real GDP per capita data from the World Bank (World Development Indicators, 2001). Besides pooled regressions, we also divided at the sample into a 10-year and 5-year interval in order to investigate the medium and short run effects. Moreover, we compared and contrasted across country groups within each of the above time frames to discern cross-sectional performance difference. We found that on average the long run real GDP per capita growth rate can be increased by 0.5 percentage point if DES is increased by 500 kcal/day. However, for a subgroup of developing countries (East and Southeast Asia) we found this number could be four times larger, while in most of the other developing countries this effect is either negative or negligible. The short run effect is more likely to be insignificant or negative than long run effect. We believe this could be due to the dynamic interaction between the short run population growth effect and the long run productivity effect. These results are robust to various econometric modeling procedures as well as to the identity critique. Since this nutrition trap is a short run effect, any policy shall aim to reduce hunger for the long run. This study shows that having chronic hunger in the country is costly in terms of economic growth in the long run.

Keywords: Nutrition, Economic growth, Human capital, and Population.

JEL Code: O11, I12, O19.

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1. Introduction

Does better nutritional status contribute to faster economic growth? If it does, what is the magnitude and persistence of this effect? These two questions are the paramount issues of this project. If indeed the answer is yes and the effect is appreciable, then food aid to those low-income food-deficit countries (LIFDCs) and least developing countries (LDCs) will not only improve the human welfare in the regions but also enhance economic growth so that they can eventually grow out of poverty.

Nutrition is the fundamental condition for human welfare. Recently, food sufficiency and easy access to food are considered as a basic human right. Good nutrition is an investment in human and social capital; solid establishment of human capital is a key determinant of household and community, which in turn builds a basis for development.

At the World Food Summit in Rome 1996, heads of state and regional representatives agreed on fighting against hunger. As the summit resolution, all possible efforts for halving hunger by 2015 were adopted by the representatives of all states and regions. According to the Food and Agriculture Organization (FAO) of the United Nations, the absolute number of undernourished in the world was 841 million in developing countries (p.45, Table 14, FAO 1996). This event shows that fighting hunger is an important and imminent issue which the current world is facing, and that there is an immediate necessity for international cooperation. At the same time, heads of state and regional representatives realize the cost of hunger; having food insufficiency at the country will hurt the economic growth. Fighting against hunger is not only an act of keeping food sufficiency for developing countries, but also for enhancing future economic growth and development.

The World Food Summit is one of the continuing efforts for recognition of the efficiency cost of hunger. The resolution of fighting against huger has sent a clear and strong message to all countries that having hunger is very costly in terms of loss in economic growth. Despite the recognition of its importance, researchers have not fully explored the interaction mechanism between nutrition and economic growth yet. In the classical growth theory, the importance of saving and investment to economic growth was pointed out long time ago. Due to the recent development of endogenous growth theory, educational attainment is well focused. If we can think of nutrition as an investment in human and social capital, then there is a strong ground for further investigation.

The rest of the paper is organized as follows. Chapter 2 reviews most of the important literature in this field. In particular, we discuss both theoretical and empirical works on how improved nutrition may increase growth, and vice versa. Various mechanisms have been discussed in the literature on how both short-term and long-term benefit may come out of a labor force with improved nutrition, which basically leads to the theoretical work in Chapter 4.

After a brief summary of data and stylized facts in Chapter 3, the main theoretical work is built up in Chapter 4. We first introduce the particular way by which the nutrition status is integrated into the growth model. Then we provide three theoretical models to analyze the potential effect of nutrition on growth. In particular, we begin with a neo-classical exogenous growth model based upon the Solow (1957) type. Nutrition status obviously can't have long-term effects because the steady state growth rate is exogenously determined by the rate of technological progress. However, this does not prevent us from discussing the faster short-term converging dynamics generated by better nutrition. In order to achieve long-term effects, we have to resort to the endogenous growth models. We first lay out the simplest endogenous growth mode, the AK model. Even though the AK model is capable of generating long-term growth out of even transitory improvement of nutrition status, it lacks short-term dynamics.[1] In order to achieve both long-term and short-term effects, we re-interpret the Uzawa (1965) and Lucas (1988) human capital growth model with nutrition associations. The basic idea is: if a labor force with better nutrition can achieve faster adoption of technology, then the long-run steady state growth rate will increase.

Empirical results are analyzed in Chapter 5. With the larger panel for DES, we divide the regression into three time subgroups: 5 years, 10 years (same as Arcand (2001)), and all 39 years (1961-1999). By doing so we could discern different impact for different time horizon. Moreover, we also compare subgroups of developing countries to understand cross section performance difference. In addition, Arcand (2001) results are compared with those produced by procedures less likely to be infected by the potential accounting identity problem. Finally, we take the feedback effect of growth rate on nutrition status into account, and both

[1] One main counterintuitive implication of AK model is that there is no convergence. At least conditional convergence has been widely accepted as an empirical regularity.

responsiveness and persistence of the feedbacks are recovered. Chapter 6 summarizes main conclusions of the paper and discusses policy implications.

2. Literature Review

Differences in cross-country growth performance have intrigued an ocean of theoretical and empirical works in this field. Two most prominent schools of thoughts are exogenous growth theory and endogenous growth theory.

Solow (1956) seminal work spurred the "convergence" frenzy. The original work implies "unconditional" convergence, which states that since all countries will come to a common steady state eventually, it must be the case that poorer countries will grow faster so that they can catch up. Even though the earlier work of Baumol (1986) found supporting this hypothesis, the results were shown to be fragile by the De Long (1988) critique.

In order to take into account differences in steady states, economists started to focus on a homogenous sample, or "augment" the conventional Solow model with variables that capture country's heterogeneity. Barro and Sala-i-Martin (1991) found evidences for convergence among U.S. states by industries as well as regions among seven European countries. Barro and Sala-i-Martin (1992) found evidences for unconditional convergence for U.S. states, and evidences only for conditional convergence for a larger cross-country sample. These conditions included initial school enrollment rate and government consumption share of GDP. Mankiw, Romer, and Weil (1992), by applying "augment" Solow model with measures of human capital, population growth rate, and physical capital accumulation rate, found that the convergence for a panel of 98 countries from 1960-1985. Most regression based on this "conditional" approach had found supporting evidences in general.

The endogenous models began with a broader definition of "capital". In addition to the physical capital, this type of models usually included a new category called "human capital". Since there was no decreasing return to scale to this broadly defined capital (sometimes increasing returns are assumed), the accumulation of capital in general would not stop at a certain level contrary to an exogenous model. Thus the growth rate was endogenously determined. In particular, more efficient human capital accumulation resulted in faster growth in the long-run. Pioneering work in the field included Romer (1986) and Lucas (1988).

For our purposes in this study, the differences between an exogenous model and an endogenous model would be whether nutrition status would have long-run effects on economic growth. If we defined that better nutrition only improved physical labor productivity, then this would cause a parallel upward shift of the growth path: even though in the short run the economy might growth faster, the long run growth rate would be unchanged. This was consistent with a exogenous growth model. However, being analogous to the idea of endogenous models, it is not difficult to imagine that a better-nutrition labor force can learn faster. If this is true, then the diminishing returns defined on a narrow definition of capital may disappear. This would produce a growth effect on the balanced path and as a result the long run economic growth rate will increase. We will discuss this in a Lucas (1988) model style in Chapter 4.

Several latest works have dealt with similar issues. Sachs and Warner (1997a) summarized current literature and came up with a list of variables that were most closely related to the economic growth. Among other commonly known variables, this list emphasized geographical and institutional indicators and human capital measures. Sachs and Warner (1997b) in particular attributed the slow growth in Sub-Saharan African countries to poor economic policies, especially a lack of openness to international markets. They also claimed this explanation made the usual African dummy variable redundant. Bils and Klenow (2000) adopted the returns to education from the labor literature to evaluate schooling's contribution to economic growth, and they found schooling explained approximately one-third of the cross-country growth differences. Hanushek and Kimko (2000) found direct measures of labor force qualify (such as international mathematics and science test scores) were strongly related to economic growth. More specifically on health and nutrition contributions to economic growth, Arora (2001) investigated the influence of health on growth paths of ten industrialized countries over the past 100 to 125 years. He found that changes in health increased the pace of growth by 30 to 40 percent permanently. Zon and Muysken (2001) combined a health production sector and a human capital production sector into the Lucas (1988) endogenous growth model. They concluded that since the steady state growth rate risen linearly in the average health-level of the population, the productivity of the health-sector was as an important determinant of growth as the productivity of the human capital accumulation process itself. Sachs et al. (2001) emphasized the importance of disease control for economic development in developing countries. Moreover, they also recognized family planning and access to contraceptives as crucial accompaniments of investments in health. We shall see below that our findings in general echo this specific notion.

3. Background and Stylized Facts

3.1 Background

The main research that we are "revisiting" in this paper is conduced by Arcand (2001). The author considers impacts of two measures of nutritional status, i.e. Prevalence of Food Inadequacy (PFI) and Dietary Energy Supply (DES), on the growth rate of real GDP per capita for 129 countries[2] from 1960s to 1980s. The author reports statistically significant and quantitatively important effect of nutrition on growth. He claims that inadequate nutrition is causing 0.23 to 4.7 percentage points loss in the annual growth rate of GDP per capita worldwide, and 0.16 to 4.0 percentage points loss for Sub-Saharan Africa in particular. These results are robust to a wide spectrum of econometric procedures[3] as well as the critique that the nutritional status measurements are widely overestimated.[4] As a result, combating malnutrition is not only an urgent task for humanitarian reasons, but also imperative for economic development purpose.

Several critiques arise upon Arcand's results. First, there is the "accounting identity" problem.[5] Since the growth rate of GDP per capita is always equal to a weighted average growth rates of agricultural, industrial, and other sector's GDP per capita, the regression of growth rate of GDP per capital on initial nutritional status is spurious given high correlation between agricultural GDP per capita and the fore mentioned two nutritional status measures.

Second, increasing DES and reducing PFI are treated as alternatives in fighting against malnutrition. Even though it is made fairly clear in the *Sixth World Food Survey* (FAO, 1996) these two measures may be complementary. DES measures daily energy (calorie) intake from food consumption, and its unit is kcal/day. The observation is the national average. PFI is the fraction of population whose daily energy intake is below a certain cutoff level. Obviously, it is possible to increase DES without changing PFI. For example, all the increases are distributed to the population above the cutoff level. Vice versa, it is possible to reduce PFI without changing DES. This could happen in a way that a simply transfer of energy intakes

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[2] 98 developing countries and 31 developed countries.

[3] These procedures are supposed to correct for unobserved country-specific heterogeneity, measurement error, and endogeneity.

[4] See Svedberg (1999).

[5] This is brought to attention by Dr. Sergio H. Lence. We thank him for providing a detailed explanation on this problem.

from those above the cutoff level to those below. The general case, at least that is what we hope to see, is that PFI decreases while DES increases. From the policy maker's point of view, it would be better to obtain the largest decrease of PFI for a given committed DES increase, or largest DES increase for a given PFI reduction. However, the actual relation between these two measures will depend on the population energy intake distribution as well as the aid distribution system. Both of them are far from being clear to outside researchers. Nevertheless we can still extract useful empirical results from actual data generated from these unknown systems.

Third, we have to admit that econometrics does not have answers to everything we would like to know. In particular, econometrics procedures can only recover statistical relations and they do not provide more useful information on the actual causality between variables, let alone the direction of the causality.[6] Even though it makes perfect sense that better nutrition enhances economic growth, we still need solid economic theories and models to formalize these relationships. These theoretical models also provide guidance on the search for possible transmission mechanisms between nutrition and growth. In particular, nutrition status is far from being exogenous, and economic growth has been widely documented to inflict its positive impact on nutrition status. For example, Easterly (1999) found that an increase in GDP per capita of 1% was associated with an increase in daily calorie intake of 538 kcal/day. All these evidences point in the direction of simultaneous determination. This leads to another related question: how responsive are those feedback effects?

Even though theoretically speaking we make a clear distinction between long-term (i.e. steady-state) and short-term (i.e. converging dynamics) growth, few empirical work has done the same. This might be due to the "observational equivalence" problem. For example, if a country suddenly grows faster, it could be that the slope of the steady state growth path is steeper, thus it indicates a "*growth*" effect. Instead, it might as well be a short-term blast to push into a higher but parallel path, thus it is only a "*level*" effect. As described in Solow (2000), even transitory growth can last for a rather long period of time.[7] Theoretical models discussed below in Chapter 4 provide rationale for both "*level*" and "*growth*" effects of nutrition status. Even though we can not identify what fraction of the growth increment is due

[6] The so-called "Granger Causality" is no exception.
[7] Most empirical results shows a annual convergence rate of about 2%. With that speed it takes about 35 years to close half of the initial income gap. See Romer (2000) page 25.

to long-term or short-term effect, it is still of great empirical importance to evaluate the impact of nutrition status on growth in various time frames. For example, in a neo-classical endogenous growth framework, given a constant annual rate of convergence, growth rate starts high, then monotonically decreases and asymptotes the long run steady state growth rate. We are going to empirically evaluate the magnitude of these impacts.

3.2 Data and Stylized Facts

We use a richer data set than that used in Arcand (2001). In particular, besides the three observation points (1969-71, 1979-81, and 1990-1992)[8] reported in the *Sixth World Food Survey* (FAO, 1996), we have also acquired average daily calorie intake per capita in most countries from 1961 to 1999. This allows us to estimate more elaborate models with improved efficiency.

We pair this data set with annual real GDP information from the World Bank dataset (World Development Indicators 2001), and this is the main panel we deal with in the paper.[9] This sample has 114 countries (27 developed and 87 developing), with 36 countries in Sub-Saharan Africa, 21 in Latin America and the Caribbean, and 5 in South Asia.

There is no doubt that a country's nutrition status is closed associated with its level of economic development. The average DES for developed economies is 3190, 3280, and 3350 kcal/day, respectively for the three-year period 1969-71, 1979-81, and 1990-92, while the counterpart for developing economies is 2140, 2330, and 2520 kcal/day.[10] Figure 1 plots the log of real GDP per capita with DES, with a dot indicating a developed economy and a plus sign indicating a developing economy. The positive correlation between these two variables is quite obvious.[11] Figure 2 plots the growth rate of real GDP per capita with DES, and it seems there is no clear correlation between them. This can be used as evidence against unconditional convergence if DES proves to be a good proxy for the initial level of real GDP per capita. Figure 3 is similar to Figure 1, but relative inadequacy (RI) of food supply in developing countries replaces DES on the horizontal axis. The negative correlation is once again quite

[8] Each indicates the average value of the variable for the three-year interval.
[9] We dropped countries with less than 1 million in population as of 1999.
[10] The Sixth World Food Survey (1996), page 11, table 1.
[11] Each observation is a country-decade. For example, Italy 1969-71 DES and its average log real GDP per capita of 1970-79. The same definition applies for the growth rate of real GDP per capita. Real GDP per capita data is from the World Bank World Development Indicator (2001).

obvious. Parallel to Figure 2, Figure 4 fails to detect any negative correlation between the growth rate of real GDP per capita and RI.

Even though the average differences between developed and developing countries have shrunk from 1.49 to 1.33 during the two decades, certain groups within the developing countries have seen the gap enlarging. In particular, Sub-Saharan African economies have experienced an absolute decrease in average DES from 2140 kcal/day in 1969-71 to 2040 kcal/day in 1990-92, as a result their differences from developed economies have increased from 1.49 to 1.64. Moreover, the two sub-groups of developing economies used to be at the bottom of the DES chart, East and Southeast Asian economies and South Asian economies, have caught up and passed Sub-Saharan African economies. By the early 1990s, Sub-Saharan African economies are at the bottom of the DES chart at the average, even though there are great varieties within the region, and South Asian economies come to the next.

We see a mirrored image in RI. In Sub-Saharan Africa, this indicator has increased from 11% to 14% during these two decades, while East and Southeast Asia has seen a dramatic decrease from 12% to 3%, and South Asia from 9% to 5%.[12] As we have made clear in Section 3.1, RI is very closely related to the dispersion of energy intake across the population, while DES only measures the average level. Simply put, it is possible to improve or worsen RI with DES intact, for example, by only changing the nutrition distribution. Figure 5 shows the empirical observation on the relation between RI and DES. The convex decreasing pattern is striking: an increase in DES is usually associated with a decrease in RI, and the reduction of RI is larger when DES is smaller.[13] If this relationship reveals indeed a social and statistic regularity that we could exploit, the improvement of average nutrition status in the poorest countries will generate a positive social effect way beyond its economic effect.[14] We will further exploit this relationship later in the paper.

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[12] The Sixth World Food Survey (1996), page 56, table 17.

[13] The simple correlation coefficient between RI and DES is – 0.82. The cubic specification provides a very good fit (t-value in parenthesis):

$$RI = 306.06 - 3.05e\text{-}1\,(DES) + 1.03e\text{-}4\,(DES)^2 - 1.16e\text{-}8\,(DES)^3$$

(15.63) (-11.95) (9.46) (-7.72)

Adjusted $R^2 = 0.91$. N = 294.

This result implies that evaluated at the 1990-92 level of DES, an increase by 500 kcal/day will reduce RI in Sub-Saharan Africa by 8 percentage points, and in South Asia by 4 percentage points.

[14] Lucas (1976) critique shows some statistical relation/regularity can't be exploited once the public has rational expectation. This renders ineffectiveness of some government policies.

Parallel to the categorization of countries into developed and developing economies, we show similar figures for Sub-Saharan countries and South Asian countries (Figures 1a, 2a, 3a, and 4a), for Low-Income Food-Deficit countries (LIFDC, Figures 1b, 2b, 3b, and 4b), and for Least Developed countries (LDC, Figures 1c, 2c, 3c, and 4c). These supplementary figures reiterate the fact that the above group of countries suffers most from malnutrition.

If we want to use DES and RI together, the only dataset available is in the one of the *Sixth World Food Survey* (FAO, 1996). There are 129 countries in the sample, 98 are developing countries and 31 developed countries. Each country has a complete observation of both DES and RI for the three three-year periods 1969-71, 1979-81, and 1990-92. In sum, there should be 387 total observations (294 for developing countries and 93 for developed countries). However, real GDP per capita data are missing for some countries for some years. The data missing percentage is 13.4% for the whole sample, 11.8% for developed countries and 13.9% for developing countries.[15] Thus developing countries are slightly under-represented. Since Sub-Saharan African countries (39 countries) and South Asian countries (5 countries) are of major interest, we separate them from the rest of the world. Sub-Saharan Africa has a data missing percentage of 13.7%, South Asia has none, and the rest of the world has 14.1%. We conclude that Sub-Saharan Africa is properly represented by the sample. We also use two other types of categorization, LIFDC (62 countries) and LDC (33 countries). It turns out that LIFDCs have a data missing percentage of 12.4% (and the rest of the world 14.4%), and LDCs have 24.2% (and the rest of the world 9.7%). We conclude that LIFDCs are slightly over-represented while LDCs are grossly under-represented. We will come back to this point when discussing estimation results.

Figure 6 depicts the transition of cross section distribution of DES for all countries during the four decades period.[16] The twin-peak structure is quite obvious, one for developing countries, and the other for developed countries. From the 60s to 70s, especially into the 80s, the difference between developing and developed countries had shrunk noticeably. But this trend is reversed in the 90s when the distribution went back to the distinctive twin-peak structure.

[15] Missing data in developed countries are mainly due to re-unification of Germany, separation of Czechoslovakia (Czech and Slovak), separation of USSR, and Yugoslavia. World Bank data do not have observations for the 70s and 80s. For the 90s, we match Czechoslovakia with Czech, and USSR with Russia. Since all measures are at per capita level, this seems to be a proper approximation.

[16] The density function is obtained by kernel smoothing technique. See Ward and Jones (1995) *Kernel Smoothing*.

This indicates that nutrition status for the developing countries has worsened in the recent years.

We want to use simple tools to address a fundamental question: Does higher DES cause faster growth, or should the direction of causality be reversed? Or maybe the effects exist in both directions? To put it in another way, what does the data tell us about the dynamics of these two variables?

Figure 7 plots the simple correlation between log DES and GDP growth rate with various time lags. In the center with horizontal mark zero is the contemporaneous correlation. To the right is the correlation of lagged growth with current DES (or to put it in another way, current growth with future DES). To the left is the correlation of lagged DES with growth (or to put it in another way, current DES with future growth). The contemporaneous correlation is about 0.12, but the forward effect is drastically different from the backward effect. In order to describe the plot clearly, this figure can be interpreted as follows. Suppose higher DES does cause faster growth. Then this effect is at the highest level during the same period as the increase in DES. This effect quickly takes off in 2-3 years. To give a quantitative example, if DES increases, once and for all, by one unit (in terms of standard deviation), in the same period GDP growth will increase by 0.12 unit (in terms of standard deviation). But this effect quickly drops to 0.08 in the next year, and 0.06 in the year after that. The long-term effect seems to be at around 0.06. But it takes much longer for the effect of economic growth on nutrition status to crop up. Similar to the above analysis, we suppose that higher growth rate does increase DES. If a one unit increase in growth rate (permanently) will increase log of DES by 0.12 unit in the same period, then in the next five-year log of DES will grow gradually, and then it settles down at the long run level of about 0.14 unit.[17] The bottom line is that these are indeed long run effects in both directions, and the effect of DES on growth shows up much faster than the effect of growth on DES, but it also decays much faster than the latter effect. On the contrary, economic growth seems to contribute to DES in a persistent way.

[17] Instead of causality, the right term to use is of course "associated". We also ignore possible feedback effects. We have also ignored the role of expectation. In a permanent income/life cycle framework, the expectation of higher future income growth may prompt an increase in DES today. Vice versa, the expectation of higher future DES may prompt faster income growth today (for example, demand for food is expected to increase, that prompt firms to produce more today.)

4. Theory

4.1 Introducing Nutrition Status into the Model

Besides DES and PFI, RI is another popular measure of nutrition status. Simply put, RI measures how far in short of the nutrition the malnutrition population is with respect to the average per capita energy requirement. Population energy intake is assumed to follow a lognormal distribution, let $f(M)$ denote this density while M is the level of energy intake. Then we have the following definition for the above three measures:

(1) $$DES = \int_0^{\infty} Mf(M)\,dM$$

(2) $$PFI = \int_0^{M_C} f(M)\,dM$$

(3) $$RI = \frac{PFI(M_a - M_u)}{DES}$$

M_c is the cutoff point below which an individual is defined as being under-nourished. It is also called the "minimum per capita energy intake requirement". M_a is the average per capita energy intake requirement. M_u is the average intake of the under-nourished. That is:

(4) $$M_u = \frac{\int_0^{M_c} Mf(M)\,dM}{PFI}$$

To put it in another way, DES measures the average energy intake of the population, PFI measures the "*prevalence*" of malnutrition, and RI measures the "*intensity*" or "*severity*" of malnutrition.[18]

We postulate the effect of nutrition on labor input the same way as in Leibenstein (1957). That is, under-nourished population can't provide sufficient effective labor input. Let L^E be a

[18] See the Sixth World Food Survey (1996) for detailed description on the derivation of the population energy intake distribution, the various types of cutoff points, Basal Metabolism Rates and activity multiplier, etc. Moreover, for better exposition, we do not consider the biological boundaries of *M*. For example, the value of *M* can not go below the survival level, and it also has a upper bound beyond which undesirable physical conditions (such as obesity) occur. We assume the distribution is not truncated in any way.

measure of total effective labor in a country, and L is the number of physical labor, and then we can define:

(5) $$L^E = \int_{-\infty}^{\infty} e(m)\phi(m) L dm$$

where m is the natural logarithm of daily energy intake M, $\phi(m)$ is the corresponding normal density of the lognormal distribution of M. In particular, if the original lognormal distribution has mean μ_M and variance σ_M^2, then this corresponding normal distribution has mean $\mu_m = \ln \mu_M - \frac{1}{2}\ln\left(\frac{\sigma_M^2}{\mu_M^2}+1\right)$ and variance $\sigma_m^2 = \ln\left(\frac{\sigma_M^2}{\mu_M^2}+1\right)$. $e(m)$ is an effective labor supply function. We further define a quadratic functional form for it:

(6) $$e(m) = \alpha_0 + \alpha_1 m + \alpha_2 m^2 \qquad e'(.) > 0,\ e''(.) < 0 \ \ \forall\, m$$

Higher nutrition improves the effectiveness of labor supply, but the marginal effect is diminishing. Substitute equation (6) into equation (5) and move L to the left hand side, we have:

(7) $$\begin{aligned}\frac{L^E}{L} &= \int_{-\infty}^{\infty} \left(\alpha_0 + \alpha_1 m + \alpha_2 m^2\right)\phi(m) dm \\ &= \alpha_0 + \alpha_1 M_m^{(1)} + \alpha_2 M_m^{(2)}\end{aligned}$$

where $M_m^{(1)}$ and $M_m^{(2)}$ is the first and second moment of variable m, respectively. According to the moment generating function of normal distribution, the above equation can be further written as:

(8) $$\begin{aligned}\frac{L^E}{L} &= \alpha_0 + \alpha_1 \mu_m + \alpha_2\left(\mu_m^2 + \sigma_m^2\right) \\ &= \alpha_0 + \alpha_1 \mu_m + \alpha_2 \mu_m^2 + \alpha_2 \sigma_m^2\end{aligned}$$

Equation (8) can be thought of as the average effectiveness per labor. Let's define $E = \frac{L^E}{L}$. Because $e'(.) > 0$ and $e''(.) < 0$, it certainly has the following property:

(9) $$\frac{\partial E}{\partial \mu_m} = \alpha_1 + 2\alpha_2 \mu_m > 0$$

(10) $$\frac{\partial E}{\partial \sigma_m^2} = \alpha_2 < 0$$

It should be obvious by now how DES, PFI, and RI may affect the average effectiveness of labor supply in the following way, respectively:

- DES is μ_M, which in turn is positively correlated with μ_m. As a result, higher DES increases the average effectiveness of labor supply.

- PFI is $\Phi(m_c)$, where $\Phi(m)$ is the normal cumulative density function and $m_c = \ln M_c$. Given DES and m_c, only a decrease in σ_m^2 can cause a decrease in PFI. Thus a decrease in PFI will also increase the average effectiveness of labor supply.

- RI is positively related to PFI and negatively related to DES, according to equation (3). Thus a decrease in RI will increase the average effectiveness of labor supply.

4.2 Neo-Classical Exogenous Growth Model

In this section we use a simple neo-classical exogenous growth model to show how the average effectiveness of labor supply, E, may affect growth rate. In such a setting the long run steady-state growth rate is determined by the exogenous rate of technological progress. As a result, higher E will not change this steady-state growth rate. However, E can still affect the short run growth by altering the gap between the new steady state. Standard result implies larger the gap, faster the growth.

First we assume output is produced with a Cobb-Douglas function with constant returns to scale with respect to capital K and effective labor EL:

(11) $$Y_t = A_t K_t^{\alpha} \left(EL_t\right)^{1-\alpha}$$

where $\alpha \in (0,1)$. A_t and L_t is the technology and labor force at time t, respectively. A_t is growing at a constant rate of g, and L_t at a rate of n. That is,

(12) $$A_t = A_0 e^{gt}$$

(13) $$L_t = L_0 e^{nt}$$

where subscript zero denotes the initial time period, i.e. t = zero.

Suppose a fixed fraction s of output is invested, and the depreciation rate of capital is δ, then the dynamics of capital accumulation is given by:

(14) $$\dot{K}_t = sY_t - \delta K_t$$

After straightforward algebraic manipulation, we can easily obtain the following results on the steady-state balanced growth path:

(15) $$\left(\frac{K}{L}\right)_t = A_t^{\frac{1}{1-\alpha}} \left(\frac{s}{\frac{1}{1-\alpha} g + n + \delta} \right)^{\frac{1}{1-\alpha}} E$$

(16) $$\left(\frac{Y}{L}\right)_t = A_t^{\frac{1}{1-\alpha}} \left(\frac{s}{\frac{1}{1-\alpha} g + n + \delta} \right)^{\frac{1}{1-\alpha}} E^{1+\alpha}$$

Obviously both $\frac{K}{L}$ and $\frac{Y}{L}$ are growing at a constant exogenous rate of $\left(\frac{1}{1-\alpha}\right) g$. Let λ be the rate of convergence, then

(17) $$\lambda = (1-\alpha)\left(\frac{1}{1-\alpha} g + n + \delta\right)$$

Equation (15) indicates that an increase in E will parallel-shift the steady-state balanced growth path of capital per labor by the same proportion, while equation (16) shows a more-than-proportional shift in the path of output per labor. Even with the constant convergence rate and steady-state growth rate, the short run growth effect can still be quite appreciable with common parameter values. For example, assume $g = 0.01$, $n = 0.01$, $\delta = 0.035$, and $\alpha = 1/3$, the convergence rate λ is equal to 0.04, and the steady-state growth rate of output per labor is 0.015 (i.e. 1.5%). Given a one-time 10% increase in E, growth rate of output per labor temporarily jumps up to 1.9%, and then decreases and asymptotes the steady-state rate of 1.5% over the long run. As mentioned before, with a convergence rate of 0.04, it takes about 18 years to close half of the initial gap. As a result, growth rate will stay above the steady-state level for extended period of time even with modest increase in E.

4.3 Endogenous Growth Model

Even though the neo-classical growth model is capable of generating higher short run growth from better nutrition, it is certainly of more interest to investigate if the long run growth performance can also be improved by even one-time increase in E. For that purpose we need to introduce the endogenous growth model. We first use the simplest version, i.e. the AK model, to illustrate the general result, and then we move on to a more specific model of human capital accumulation. We note that the first example of including undernourishment in a Neoclassical or "AK" endogenous growth model is Arcand (2001), upon whom the following two sections are entirely based.

4.3.1 AK Model

AK model is the simplest endogenous growth model, but it is sufficient to produce the basic results. Without loss of generality, we assume physical labor $L = 1$, no population growth, and the technology level is a constant A. As a result, total effective labor L^E is equal to E, and the production function takes the form:

$$Y_t = AEK_t \tag{18}$$

and the dynamics of capital accumulation is given by:

(19) $$\dot{K}_t = AEK_t - C_t$$

where C_t is consumption at time t, and obviously we have assumed zero capital depreciation for simplicity. Further assume that the instantaneous utility function takes the constant relative risk-aversion (CRRA) form, and the infinitely lived representative consumer maximizes the following time-separable inter-temporal utility function with exponential subjective discount rate ρ:

(20) $$\int_0^\infty e^{-\rho t} \frac{C_t^{1-\gamma}}{1-\gamma} dt \qquad \gamma > 0, \ \gamma \neq 1$$

The choice variable is C_t, the state variable is K_t, and the representative consumer maximizes Equation (20) subject to Equation (18) and (19). Set up the present value Hamiltonian function:

(21) $$H_t = e^{-\rho t} \frac{C_t^{1-\gamma}}{1-\gamma} + q_t \left(AEK_t - C_t \right)$$

where q_t is the co-state variable. It measures the shadow price of capital at time t. The following are the three optimality conditions:

(22) *Static Condition:* $\frac{dH_t}{dC_t} = 0$

(23) *Euler Equation:* $\frac{dq_t}{dt} = -\frac{dH_t}{dK_t}$

(24) *Transversality Condition:* $\lim_{t \to \infty} K_t q_t = 0$

Using these conditions we can easily derive the following result:

(25) $$\frac{\dot{C}_t}{C_t} = \frac{AE - \rho}{\gamma}$$

Equation (18) and (19) obviously imply that both Y_t and K_t are growing at the same rate as C_t on the balanced growth path. Equation (25) implies that even a one-time improvement in nutrition status will have permanent effect on the long-term growth rate. Even though AK model is convenient in generating permanent effect from temporary changes in *E*, it lacks short-term dynamics. It is easy to prove that in this model C_t will always be a constant proportion of K_t. Thus if at some future time *t' E* jumps up permanently, C_t will simply change from the old proportion to a new proportion of K_t instantaneously, and then move along the new faster growth path. That is equal to say, the balanced growth paths of C_t, K_t, and Y_t will show kinks of the same degree at the time of *t'*, but the ratio between them is always constant. Since at least conditional convergence is a widely accepted fact, this is the major failure of AK model.

4.3.2 Human Capital Model

There is no doubt that better nutrition improves physical health.[19] Several researches have found evidence that healthier labor force could increase productivity. As observed by Grossman (1972), the positive contribution of a "good health" to labor productivity is of particular importance to economic growth. Even though the point is well taken that better educated people can learn faster (See for example Lucas (1988) and Barro (1991), among others), it is natural to argue that being healthy is just as important as being knowledgeable as far as economic growth is concerned. With limited resources it seems they are substitutes, but from the perspective of economic growth they act more like complements. In this section we shall introduce a nutrition index (as a proxy for the healthiness of labor force) into the standard human capital accumulation framework and obtain a new interpretation from the model.

This two-sector endogenous growth model originates from Uzawa (1965) and Lucas (1988). In particular we follow Barro and Sala-i-Martin (1999) in the following description. There are two sectors in the economy. One sector uses both physical capital *K* and human capital *H* to produce output *Y*. This output can be used for consumption or physical capital investment. The production technology in this sector is Cobb-Douglas with constant return to scale with

[19] We treat an increase in daily energy intake as the same meaning as better nutrition. This is obviously not always true. For example in some developed countries excessive intake of calories has caused obesity. However, since we are mainly focusing on the developing countries, especially those with food shortage, this problem is of less importance.

respect to K and H. Human capital is "*produced*" in the second sector only with a fraction $1 - u$ of total H, the rest of it is used in the first sector for regular output production. No physical capital is needed in the human capital production. Both types of capital depreciate at the common rate of δ for simplicity. To summarize the model:

$$Y = AK^{\alpha}\left(uH\right)^{1-\alpha} = C + \dot{K} + \delta K \tag{26}$$

$$\dot{H} = B\left(1-u\right)H - \delta H \tag{27}$$

A is the total factor productivity in regular goods production, while $B(1 - u)$ is the gross marginal product of existing human capital in new human capital production. We believe that the nutrition status may affect both the marginal product parameter B and the human capital depreciation rate δ. That is, B is an increasing function of E, while δ is a decreasing function of E. As we have argued before, healthier labor will learn faster, thus the accumulation of human capital is faster. This is equivalent to an increase in the parameter B. For example, better nutrition can enhance the contribution of schooling to human capital accumulation. Moreover, better nutrition may also reduce the human capital depreciation rate δ. Various researches have shown that countries with better nutrition usually have longer life expectancy. Longer life expectancy basically extends the time horizon within which the benefit of human capital accumulation can be harvested. As a result, better nutrition provides stronger incentive for human capital accumulation.

In order to describe the steady state, it is easier to do the following variable transformation:

$$\omega \equiv \frac{K}{H} \tag{28}$$

$$\chi \equiv \frac{C}{K} \tag{29}$$

From Equation (26) and (27) it is straightforward to derive the following steady state growth rates of K and H:

$$\frac{\dot{K}}{K} = Au^{1-\alpha}\omega^{-(1-\alpha)} - \chi - \delta \tag{30}$$

(31) $$\frac{\dot{H}}{H} = B(1-u) - \delta$$

Assuming the same CRRA utility function for each representative consumer, and that these equations go through the same optimization procedure described in the previous section, we obtain the optimal growth rate of consumption on the balanced growth path:

(32) $$\frac{\dot{C}}{C} = \frac{\alpha A u^{1-\alpha} \omega^{-(1-\alpha)} - \delta - \rho}{\gamma}$$

Hence, from the definition of ω and χ, and the optimization conditions, we obtain:

(33) $$\frac{\dot{\omega}}{\omega} = A u^{1-\alpha} \omega^{-(1-\alpha)} - B(1-u) - \chi$$

(34) $$\frac{\dot{\chi}}{\chi} = \frac{(\alpha-\gamma) A u^{1-\alpha} \omega^{-(1-\alpha)} + \chi - \left[\delta(1-\gamma) + \rho\right]}{\gamma}$$

(35) $$\frac{\dot{u}}{u} = \frac{B(1-\alpha)}{\alpha} + Bu - \chi$$

Steady state values of ω, χ, and u can be solved by setting $\dot{\omega} = \dot{\chi} = \dot{u} = 0$, and with the simplifying notation:

(36) $$\varphi \equiv \frac{\rho + \delta(1-\gamma)}{B\gamma}$$

We obtain:

(37) $$\omega^{*} = \left(\frac{\alpha A}{B}\right)^{\frac{1}{1-\alpha}} \left(\varphi + \frac{\gamma-1}{\gamma}\right)$$

(38) $$\chi^{*} = B\left(\varphi + \frac{1}{\alpha} - \frac{1}{\gamma}\right)$$

(39) $$u^{*} = \varphi + \frac{\gamma-1}{\gamma}$$

Substituting Equations (37), (38), and (39) into Equation (30), (31), (32), and (26), we obtain the steady state value of net marginal product of physical capital in goods production, r^*, as well as the common growth rate of C, K, H, and Y, g^*:

$$r^* = B - \delta \tag{40}$$

$$g^* = \frac{B - \delta - \rho}{\gamma} \tag{41}$$

Thus an increase in B or a decrease in δ, both can be achieved by better nutrition as argued before, and they will increase the steady state marginal product of physical capital and long run growth rate. For empirically reasonable values of ρ, δ, and γ, φ should be positive. Hence Equations (37), (38), and (39) imply that an increase in B will reduce ω^* and u^*, but increase χ^*. The intuition behind these changes is quite obvious. Higher B makes human capital accumulation more appealing, thus a larger fraction of human capital is devoted into the second sector. As a result, human capital temporarily grows faster than physical capital so that the ratio $\frac{K}{H}$ drops. The $\frac{C}{K}$ ratio is higher basically because of the dominance of human capital effect over physical capital effect.

Unlike the AK model, the current framework is also capable of generating desirable transitional dynamics. The detailed derivation is tedious and of little interest to this project, so we just report the main results below.

The transitional dynamics is implicit in the three-equation system (33), (34), and (35). In order to see the convergence clearly, we need another variable transformation. We can define this one as follows:

$$z \equiv A u^{1-\alpha} \omega^{-(1-\alpha)} \tag{42}$$

Obviously, αz is the gross marginal product of physical capital in goods production. We can rewrite the three-equation system using z:

(43) $$\frac{\dot{z}}{z} = -(1-\alpha)\left(z - z^*\right)$$

(44) $$\frac{\dot{\chi}}{\chi} = \left(\frac{\alpha-\gamma}{\gamma}\right)\left(z - z^*\right) + \left(\chi - \chi^*\right)$$

(45) $$\frac{\dot{u}}{u} = B\left(u - u^*\right) - \left(\chi - \chi^*\right)$$

where z^* is the steady state value of z. By Equations (37), (39), and the definition of z in Equation (42), we can define z^* as follows:

(46) $$z^* = \frac{B}{\alpha}$$

The new three-differential-equation system of Equations (43), (44), and (45) clearly defines a converging system for usual parameter values of α, γ, and B. In particular, the growth rate of Y can be shown to follow:

(47) $$\frac{\dot{Y}}{Y} = g^* + \alpha\left(z - z^*\right) - \left(\chi - \chi^*\right)$$

Furthermore, numerical results show that the relation between the growth rate of Y and ω tends to be U-shaped with minimal growth rate of Y achieved at ω^*. That is to say, no matter ω starts below or above ω^*, the growth rate of Y will start high and then gradually reduce to g^*. This implies an overshoot of short run economic growth rate as a result of an increase in B or a decrease in δ.

To summarize the general results in this section: an increase in nutrition status not only can increase economic growth rate permanently, but also the short run effect will be greater than the long run effect.

5. Empirical Results

5.1 Introduction

The Post-WWII economic history is full of growth miracles and disasters. Ever since Solow (1956) seminal work, economists have made significant progress in understanding difference in cross-country economic growth. Most of these new understandings, including the so-called unconditional and conditional convergence, can be illustrated with the following simple model, and we shall use this as our starting point of empirical analysis.[20]

Assume that each economy has a balanced-growth-path upon which every variable grows at a constant rate, and this steady state value of physical capital is equal to k_i^*, where subscript "i" represents "country i". At any point of time t, deviation of actual k from the above steady state value will generate the following convergence growth:

$$\dot{k}_{it} = \lambda[k_i^* - k_{it}] \tag{48}$$

where a dot on top of a variable represents the time derivative of that variable, and λ is the rate of convergence. Consider between time 0 and T, we have:

$$k_{iT} - k_{i0} = (1 - e^{-\lambda T})[k_{i0}^* - k_{i0}] + \int_{\tau=0}^{T} (1 - e^{-\lambda(T-\tau)})\dot{k}_{i\tau}^* d\tau \tag{49}$$

Equation (49) decomposes potential sources of economic growth into two parts. The first term on the right hand side captures the pure convergence effect. That is, growth rate depends on the country's initial position relative to its (initial) balanced growth path. The second term captures the changes in steady state may also spur growth. Moreover, earlier changes yield larger effect than later changes.

Even though the above example is given in the form of physical capital, the same idea can be easily extended to include human capital and efficiency. The basic conclusion is that a country's growth depends on its starting points relative to the balanced growth paths, as well as changes in those balanced growth paths. The variables included in the first term, those used

[20] This part follows Romer (2001) and Barro and Sala-i-Martin (1999).

to represent the initial state of the economy, are called “state variables”. On the other hand, variables included in the second term, those to represent the subsequent changes in the steady state, are called “control”, “environmental”, or “fundamental” variables. The group of work that assume common steady state for all countries is called “unconditional” convergence analysis, while a study which controls for country-specific steady state is called “conditional” convergence analysis.

Most of the current literature that adopts the convergence analysis approach to explain cross-country growth differences differs only in their choices of the above state and control variables. But it is not uncommon to see results based only on the variables of specific interest. This is problematic because omitted variables, especially those found to exert significant effect on growth, will produce biased (inconsistent) and inefficient estimates on parameters of interest. However, we have no intention to dig out all the important variables that can explain growth. After all, unless simultaneous system is adopted, including variables that are closely related to nutritional status will obscure the full effect. Fortunately several latest works have been quite successful in revealing the appropriate list of variables that should be included in the regression. We shall draw heavily on those works below. Barro and Sala-i-Martin (1999) have a detailed description on the choice of these variables. On the other hand, among other authors, Islam (1995) discusses the methodology of using panel data for growth convergence analysis. Arcand (2001) has also shown a battery of econometric methods to correct for potential problems.

5.2 Regression Results

We are interested in heterogeneities in two dimensions. First of all, we would like to know how time frame plays a role in the estimated effect. As we mentioned before, the nutrition status may improve growth in a gradual manner. As a result, the short run and long run impact may be different. Investigating different time frames produces a better exposition of the whole dynamics. Secondly, we are interested in how different countries (or groups) perform differently in terms of contribution to nutrition improvement. Identifying sources that make such a distinction can help understand the difference in cross section growth performance.

We begin with the long run case of 40 years, from 1960 to 1999. Then we move on to more the frequent sample of 10 years and 5 years. In each case we also divide the countries into subgroups so that sources of cross section differences can be identified.

5.2.1 Pooled Regression: 1960-1999

Table 1a summarizes the result for the 40-year long run analysis. We first calculate the growth rate of real GDP per capita from the latest World Bank dataset. Initial GDP per capita is real GDP per capita for the year 1960. Initial DES comes from the FAO's web site[21], and the starting year is 1961. We use the DES of that year as the initial value. In order to mitigate the effect of random measurement error in DES, we also tried using the average of 1961 and 1962 as the initial value. The same experiment is conducted with initial real GDP per capita.

In order to take into account "environment" changes, we add some popular variables on the right hand side of the regression. Investment share, trade share, and population growth rate are all from the latest World Bank dataset. Since investment share is the real investment share of GDP, it serves as a proxy for the saving rate in the augmented Solow model. Everything else held constant, a higher saving rate results in a higher steady state, thus faster growth given the same initial position. Population growth will have exactly the opposite effect. None of them is supposed to affect the long run growth rate in a Solow framework.

If we deviate from the exogenous growth framework and adopt the endogenous growth model, such as the AK model and the human capital accumulation model discussed in the previous chapter, saving rate and population growth rate may have a long run effect. Either way, their impact on economic growth is predictable.

We also need some other variables to proxy for the "fundamental" changes that will permanently enhance the long run growth. One of them is of course DES. We speculate that better nutrition may improve the quality of labor and expedite the accumulation process of human capital, thus the country may enjoy faster long run growth. We have also experimented with trade share of GDP on the rationale that foreign trade may serve as an additional growth

[21] One can find FAOSTAT on Internet at http://apps.fao.org/

engine. But it turns out that it does not add much to the model, and so it is not reported in the result.

Finally, we add some dummy variables to account for regional effects. We also add a dummy for developing countries to check if there is any omitted effect for this specific group of countries.

Evidence for conditional convergence is only weakly significant. After controlling for the "fundamentals", countries with a lower initial income tend to grow faster. If a country's initial income is 1% less than another country with the same fundamentals, it is going to grow 0.3-0.5 percentage points faster on an annual basis. Investment share contributes positively, while population growth contributes negatively to the economic growth. Quantitatively, if investment share increases by 10 percentage point, the long run growth rate will increase by 1-2 percentage points, while a 1 percentage point increase in population will reduce economic growth by 0.3-0.5 percentage points. This is consistent with most of others' findings.

Initial DES does have modest positive effect on economic growth. The estimates imply that an increase of 500 kcal/day of energy intake will increase the annual growth rate by 0.4 percentage points. Over 40 years, this translates into a 17% difference.

If we can treat location dummies as picking up specific fundamentals for countries within the area, then it seems that all three regions (Sub-Saharan Africa, Latin America and the Caribbean, and South Asia) are converging to a relatively lower steady state. If we believe 40 years is close enough to the long run situation, these specified groups of countries have permanently lower growth rate. As discussed in Cho and Graham (1996), the poorest countries are converging to lower steady states from above, while the richest countries are converging to higher steady states from below. That is why growth rate is stalled for some developing countries. As a matter of fact, they are very close to their (low) steady state; the only thing that can boost the economic growth is by improving the "fundamentals". As we can see very clearly from Table 1a, increasing DES is a candidate for achieving that goal.

Finally, after adding those three location dummies, the developing country dummy has a negligible effect on growth. This implies that other developing countries are actually growing at a comparable rate with the developed countries after controlling for the first four variables (initial log GDP, initial DES, investment share, and population growth).

We also use the specification in column 1 on the subgroups of developing and developed countries. The result is reported in Table 1b. Even though the convergence effect, savings, and population growth assume the usual signs, initial DES does not contribute further to the long run growth. The null of constant parameters across these two groups of countries can't be rejected at the usual confidence level.[22]

In Table 1c we estimate separately for the subgroup of Sub-Saharan Africa, Latin America and the Caribbean, and East and Southeast Asia. Only the latter group has shown positive impact of initial DES on long-term growth. This is also the group of countries that have experienced the fastest growth in DES during the four decades period. In particular for this group, the magnitude of DES' impact on economic growth is almost 5 times larger than the full sample average reported in Table 1a column (3). This translates into a 1.7 percentage point increase in annual economic growth, and amounts to a 96% difference in 40 years.

5.2.2 Panel Regressions: By Decade

In this section we divide the sample period into the four decades, i.e., 1960-69, 1970-79, 1980-89, and 1990-99. We use the DES in 1961, 1970, 1980, and 1990 as the initial value for each decade, and the logarithm of real GDP per capita in 1960, 1970, 1980, and 1990 as the initial value for each decade. Investment share and population growth rate are decade average values.

Table 2a reports the OLS result. Column 1 is the pooled regression, while column 2 to 5 are independent regressions for each decade. The null that the four decades have the same coefficients is rejected at the usual level of confidence.[23]

Location dummies indicate that Sub-Sahara African growth rate is particularly low in the 60s, 70s, and 90s. While in Latin America and the Caribbean the worst period is the 60s and 80s. For South Asia, the 70s and 90s has seen the worst growth rates. Investment share has shown

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[22] $F(5,77) = 0.65$. Not reported in the table.
[23] $F(8, 348) = 14.86$.

constantly significant positive effects, while population growth mostly exerts negative impact on growth.

The effect of the initial log GDP is mostly not significant. The convergence effect is not significant for three out of four decades. The initial value of DES is even more puzzling because none of the positive effects is significant; the negative effects are quite significant for the 80s. In the pooled estimation the initial impact of DES is significantly negative. This is drastically different from the long run result. This difference implies that the short run and long run impact may diverge. Theoretically speaking, the positive effect of initial DES on growth given initial GDP derives from its positive impact on the quality of human capital. However, if it also serves as a good proxy for the initial value of GDP, it could yield negative effect. These mixed and puzzling effects call for more elaborate estimation procedures.

We use LSDV[24] (Least Square Dummy Variable), ITGMM (Iterative Generalized Method of Moment) with instrumental variables, and IT2SLS (Iterative Two-Stage Least Squares) to estimate the four-decade panel. The purpose of LSDV is to account for unobservable individual heterogeneity, while GMM can correct for possible measurement error problems. Iterative algorithms are adopted to improve small sample properties of the estimates. In both the ITGMM and IT2SLS procedures we take first difference across time, and then use the GDP and DES values lagged for 2 periods as instruments.

The results reported in Table 2b reinforced those in Table 2a. LSDV estimation reveals faster convergence than that from OLS method. This implies that the unobservable individual effect contaminated the estimates in column 1 of Table 2a. However, the negative coefficients for initial DES are very similar to that of Table 2a. Moreover, both ITGMM and IT2SLS find significantly negative coefficients on initial DES.

Parallel to the long-term analysis, we also run separate regression on developing and developed countries, and the result is reported in Table 2c. Neither group shows positive impact of initial DES on growth. The negative aggregate shock of the 80s and 90s seem to be quite evenly distributed.

[24] Also called the "within" or "fixed effect" estimator.

Table 2d shows the group-wise result for Sub-Saharan Africa, Latin America and the Caribbean, and East and Southeast Asia. Similar to the findings for long-run growth, the positive impact of initial DES only shows up for the East and Southeast Asian countries. This magnitude of the effect is also quite large. This number implies that a 500 kcal/day increase in DES will increase the average growth rate of the next 10 years by 1.9%. On the other hand, the DES coefficients for the SSA and LAC group are negligibly small and insignificant.

5.2.3. Panel Regression: By Quinquennial

We further divide our sample into eight five-year intervals. Estimation results are reported in Table 3a and 3b. These results are in general consistent with those of the by decade estimation.

First of all, in the pooled regression, the impact of initial DES on the average growth rate of the following five years is not significantly different from zero. Inclusion of quinquennial dummies and country group dummies yield more detailed information about the aggregate shocks and (group) idiosyncratic shocks. The aggregate shock turns strongly negative from 1975-1979, and reaches the bottom during 1980-1984. Since then it has subsided somehow, but still significantly negative by 1999. Once these aggregate shocks are included, some of the country group dummies are no longer significant. The Sub-Saharan Africa dummy is not significantly different from zero now. This indicates there is no particular negative idiosyncratic shock to this group of countries. An interesting finding is that the East and Southeast Asia group of countries has experienced significantly positive idiosyncratic shocks.

When fixed-effect model (LSDV) is used, the initial DES impact turns negative, though not very significant. Income convergence effect is surprisingly strong given the short time horizon. The dummy for 1995-1999 is no longer significant, indicating that there is no negative shock at the global level, and that the individual (country) heterogeneity has picked up that effect.

We have also estimated the model for some sub-groups of developing countries. We obtain similar result as before: initial DES only shows a significantly positive impact for East and Southeast Asian countries. The magnitude of the estimate is also very similar to the 40-year and 10-year estimates. Another interesting finding is, despite the fact that the Sub-Saharan African and Latin American and the Caribbean countries suffered from negative shocks from late 70s until present, East and Southeast Asian countries seem to be able to avoid that. The appreciably negative shock for this group of countries only appeared in the last five-year period.

5.2.4 A Simple Granger Causality Experiment

Convergence regression is only suitable for revealing long run relations, so we want to deviate from that method momentarily and instead try to find out more about the short-term relations. In particular, we use the simple Granger Causality model to focus on the two time series, i.e. DES and GDP, on the annual basis.

Table 4 reports the SUR result of a Granger Causality test. We arbitrarily choose a 5 year time lag for both equations. In terms of “time precedence”, we can’t reject that there is causality in both directions. Relatively speaking, the impact of growth on DES is more significant than that of DES on growth, at least for the short run.

5.3 The Accounting Identity Critique

Real GDP per capita growth is a weighted sum of growth in agriculture, industry, and service sectors. Thus running a regression of “total” growth on its component is spurious because of this identity relationship. Since DES is calculated from the food consumption balance sheet, it is highly correlated with a country’s agriculture productivity. As a result, the above regressions may fall into this identity critique.

We here propose two methods to evaluate the validity of this critique. We first remove the agricultural component from total growth, and re-estimate the model. That is, we only use the industry plus service part of real GDP to evaluate the impact of initial DES. If now DES has a positive impact on growth, it can’t be a mirage effect from agricultural growth. Second, we maintain the integrity of the left-hand-side variable, but purge any information about agricultural growth out of DES, and only use the information orthogonal to agricultural growth in the estimation. In particular, we replace DES with the residual from a first-step regression of DES on agricultural GDP. Shares of agriculture, industry, and service in GDP are available for each country on annual basis in the World Bank data set. We will re-estimate both the long run (40 years) and medium run (10 years) models.

5.3.1 Growth Without Agricultural Component

Column 1 of Table 5a reports the long-term (40 year) convergence regression with OLS. Since agriculture share data is missing in many countries for the beginning year of 1960, only 42 countries (out of 114) are included in the final estimation. This sample size is too small to do further sub-group analysis, so we will only use the decade panel for sub-group estimation.

Comparing with column 2 in Table 1a, income convergence is faster, and the initial DES effect is the double as before and more significant. So for the long-term regression, removing agriculture sector enhanced the effect of initial DES.

Column 2 is comparable to Table 2a column 1. Income convergence is faster, and the initial DES effect changes from significantly negative to insignificantly negative with the magnitude drops in half. This also indicates that instead of weakening the positive effect, it is weakening the negative effect.

Column 3 is comparable to Table 2b column 1. The initial DES coefficient, both the estimate and t-value, are very similar. Removing the agriculture sector does not do much to the impact of initial DES on growth.

Table 5b is parallel to Table 2d. We run separate regression for the sub-group of developing countries of SSA, LAC, and ESEA. For the first two groups, the negative initial DES coefficient is ten times larger in absolute value, but it is still statistically insignificant. For the last group, i.e. East and Southeast Asia, the rate of convergence is higher, and the positive effect of initial DES on growth is larger. This enforces the finding that the positive effect only exists for this group of countries.

To summarize, most of the regressions indicate that removing the agriculture component from real GDP per capita does not change the basic findings. In particular, for the group that shows significant positive effect of initial DES on growth, the effect is actually larger. Moreover, in the long-run (40 years) regression, the positive effect is larger and more significant. By attempting to correct for the identity problem, we actually have re-enforced our previous findings.

5.3.2 DES Orthogonal to Agriculture Productivity

Daily energy supply is closely related to a country's real agricultural GDP per capita. This is also the source of possible identity problems aforementioned. In this section we purge DES off the component of real agricultural GDP and only use the residual in the growth regression. This residual could reflect distributional properties of food supply in a country and we believe it is uncorrelated with the level of agricultural development. In a sense this resembles an exogenous DES shock such as food aid from abroad.

We first regress DES on real agricultural GDP per capita, and save the residual. The footnote of Table 6a reports this first step regression for the long-term sample and the by decade sample respectively. Both quadratic functions show the usual concave shape. We use the residual from these quadratic regressions as the DES in the second step estimation.

Table 6a is parallel to Table 5a. Comparing the corresponding columns in these two tables, we find little difference between them. In particular, for the long-term sample shown in column 1, contribution of initial DES to long-term growth is at the range of 1e-5, and both estimates are slightly significantly different from zero. Column 2 and 3 are quite similar too. One interesting observation is that once the individual unobservable effect is included, decade 80 and decade 90 dummies are much less significant. This indicates that the negative shocks during these two decades are country-specific, not time-specific.

Table 6b once again focuses on the three subgroups of developing countries. The only substantial change is that for East and Southeast Asia countries the impact of initial DES on growth is cut in half, but still very significant. In addition, these two estimates are much larger than those obtained from the long-term regression. This difference comes from two sources. One is that this group of countries might be enjoying a higher rate of return from the improved nutritional status. Second, it could also imply that the short run effect may be different from the long run effect. We are going to come back to this point in a later section.

5.4 Simultaneous Estimations[25]

[25] It will become clear that this is a misnomer because only lagged dependent variables enter as independent variable.

Empirical results from the previous section revealed two features of the relation between nutrition status (i.e. DES in particular) and GDP growth. One is that these two are jointly determined, and the second is that there exist lagged effects. That is, the economy may have to grow for a while before the population nutrition status to improve,[26] and in the meantime nutrition status has to improve substantially before its effect on economic growth show up. In this section we combine the growth equation with a simple nutrition equation into a simultaneous equation type model. Both structural parameters and most probably lags will be recovered from this estimation.

We postulate the following equation system:

(50) $$g_{it} = \alpha_0 + \alpha_1 s_{it} + \alpha_2 n_{it} + \alpha_3 des\{L = \tau_g\} + \varepsilon_{git}$$

(51) $$des_{it} = \beta_0 + \beta_1 g\{L = \tau_d\} + \varepsilon_{dit}$$

g_{it} is the growth rate of real GDP per capita for country "i" at time "t". s_{it} is the investment share of GDP, n_{it} is the population growth rate. $des\{L=\tau_g\}$ is a lag indicator function. For example, if $\tau_g = 2$, then this formula is equal to des_{t-2}. That is, DES' impact on growth has a two years lag.[27] $g\{L=\tau_d\}$ has a similar interpretation: we assume that growth impact has a τ_d period lag on nutrition status. α's and β's are parameters to be estimated. We further assume that the error terms, ε_{git} and ε_{dit}, follow a bivariate normal distribution with zero means, standard deviations σ_g and σ_d respectively, and correlation coefficient ρ_{gd}. Two-equation joint estimation is more efficient than single equation estimation as long as the correlation coefficient is not equal to zero.

First assume we know (τ_g,τ_d). Then the log likelihood of the bivariate normal distribution is:

(52) $$\begin{aligned} &LL\{\alpha's, \beta's, \sigma_g, \sigma_d, \rho_{gd} \mid g, des, s, n\} \\ &= -\ln(\sigma_g \sigma_d \sqrt{1-\rho_{gd}^2}) - (\varepsilon_g^2 + \varepsilon_d^2 - 2\rho_{gd}\varepsilon_g\varepsilon_d)/(2(1-\rho_{gd}^2)) \end{aligned}$$

[26] This could be due to a growth trap.

[27] This specification has the problem of ignoring anything beyond period τ_g, but adding more lagged variables quickly increases the computation burden. We did report the case that includes an additional lag.

where

(53) $$\varepsilon_g = (g - \alpha_0 - \alpha_1 s - \alpha_2 n - \alpha_3 des\{L = \tau_g\}) / \sigma_g$$

(54) $$\varepsilon_d = (des - \beta_0 - \beta_1 g\{L = \tau_d\}) / \sigma_d$$

For each given pair of (τ_g,τ_d) we find the set of parameter values that maximize equation (52) given the data on GDP growth rate, DES, investment share, and population growth rate.[28] Then we choose the pair of (τ_g,τ_d) that has the maximal log likelihood as the most probable value of lags.

Three types of regression results are reported in Table 7. Column (1) is a standard regression with equations (52), (53), and (54). In column (2) we have dropped the population growth for reasons that shall become clear later on. In column (3) we add an additional lag into the right hand sides of both equation (50) and (51) to see the robustness of our results reported in column (1).

Coefficients in column (1) are consistent with our previous results. Note that in order to facilitate computation, we have multiplied the GDP growth rate by 100. Thus in comparable terms the coefficient for investment share is about 0.002, and that for population growth is about –0.0013. Both have the usual signs, and the magnitudes are very close to previous estimates. Since this is basically a short run model, the coefficient for lagged log DES is significantly negative. The most probable DES lag for this equation is two years. For the second equation, i.e. the DES equation, lagged growth rates do improve DES significantly, and the most probable lag for this effect is 5 years. This result is also consistent with Figure 7.

As we mentioned before, forcing the correlation to be fixed at one period may be problematic. We thus add an additional lag into the right hand sides of both Equations (50) and (51). That is, g depends on both log DES lagged τ_g period and τ_g+1 period. But in order to maintain easy computability, we restrict them to have the same coefficients. That is equal to say, we assume g depends on the average of log DES of period τ_g and τ_g+1. The same for equation (51), we add the growth rate of GDP for period τ_d+1 to the right hand side, with the same coefficient as that for period τ_d. Column (3) reports the result. Except that the negative sign for coefficient of lagged log DES has become insignificant, this result is almost the same as that reported in column (1). Another minor change is that the most probable lag for the second equation is 4 years instead of 5 years now. Since in this specification a 4 years lag includes the 5 years lag by construction, this does not pose a contradiction to the previous result.

Why would an increase in DES decrease economic growth rate in the short run? We suggest the following story. An increase in DES can improve the health condition of the population, thus reduce the mortality rate of the population. With children's mortality rate decreases while elderly people live longer, this is equivalent to population growth. Even though better nutrition is supposed to raise labor productivity and fasten human capital accumulation, these long run effects will not outrun the short run effect on mortality rate. As a result, mortality effect will dominate the short run, and faster population growth quickly eats up any modest amount of productivity growth. This could render the negativity of the short run coefficient for DES. In the long run, mortality effect will diminish and children's mortality rate and life expectancy will stay at the "natural" rate. The productivity effect becomes the dominant force and this renders the positive coefficient for the long run model.

The above argument is at least partially supported by the regression results shown in column (2). We dropped the population growth, so now the DES coefficient should have picked up both the mortality effect and the productivity effect. Comparing with the coefficient in column (1), it becomes mildly more negative and drastically more significant. If we compare column (2) with column (3), including the population growth variable has made the lagged DES coefficient insignificantly negative. This indicates that the negative short run effect of DES on growth is mainly due to its impact on short run population growth.

Finally, Figure 8 is a three dimensional graph on the choice of (τ_g,τ_d) for column (1). The final choice of (2,5) is obviously the peak of the surface. However, the lag in the growth equation (with lagged log DES) seems to be much more robust than that in the DES equation (with lagged growth) because the likelihood does not change much from changes in log DES lags. As a result, τ_d equal to 2 may be a fragile result.

5.5 Nutrition and Population Growth

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[28] The Maximum Likelihood Estimation routine we use is GAUSS MAXLIK.

Two puzzles come to mind from the full spectrum of regression results. First, why is the impact of nutrition on growth negative (or close to zero) in the short run while it is positive in the long run? Second, why for some countries this effect is positive while for others negative?

We believe the answer lies with the relation between population growth and nutrition, both in the short run and long run, and in the relation between productivity growth and nutrition, also both in the short run and long run. Consider a typical developing economy in which there is severe food shortage. Population growth is low due to high children's mortality and widespread malnutrition-related illness (or simply starvation). When nutrition condition starts to improve, it is going to have instant impact on the above two factors, thus population growth is going to rise. Unless this nutrition improvement can also immediately enhance food production, the previous nutrition status is not sustainable. That is, increased population will quickly "eat up" the additional nutrition and this reduces the overall nutrition status. This constitutes a "nutrition trap".[29] If nutrition improvement is not big enough, or can not be transformed into productivity soon enough, the nutrition status will be stuck in the low equilibrium, thus its impact on productivity will be negligible.

We use the by-decade information on initial DES and population growth for the following 10 years to estimate a quadratic function. The result is:

$$n = -350.5426 + 92.9095 \text{ (log DES)} - 6.1106 \text{ (log DES)}^2$$
$$(-4.29) \qquad (4.44) \qquad\qquad (-4.56)$$
$$\text{Adj. } R^2 = 0.19$$

This result implies an "inverse-U" shaped relation between population and DES. Figure 9 shows the estimated function for DES from about 1500 to 4000.[30] Before reaching the peak of the function, an increase in DES will increase population growth, thus it is likely to be stuck in the low nutrition trap. The function reaches its peak at around 7.6, which is about 2000 kcal/day. Table 8 reports countries that fall into this category for the four decades covered in the sample. Sub-Saharan Africa has seen about one-third of the countries in this category, and

[29] Technically, a nutrition trap can be defined as phenomena of a mild decrease in DES after one shot increase in DES.
[30] $\ln(1500) \approx 7.3$, $\ln(4000) \approx 8.3$.

little has changed for the past four decades. In the meantime, East and Southeast Asian countries have mostly escaped from the trap.

Figure 10 shows the by-decade and by country-group nutrition level changes and the population growth rate. Each pair of twin-bar is for a country-group and a specific decade. The left bar is DES level, while the right bar is the population growth rate (multiplied by 1000). It is obvious that Sub-Saharan African countries have experienced substantial increases in population growth, and that should be a important reason for the almost constant DES level during the four decades. On the other hand both Latin American and the Caribbean and East and Southeast Asian economies are able to reduce the population growth rate continuously, thus their DES per capita is constantly improving.

In the long run both nutrition (as measured by DES) and population growth rate will stabilize at some constant level. For example, there is an optimal nutrition intake for biological and anthropological reasons, and the birth/death rate will also be determined by "natural" forces. All of these factors are beyond the scope of economics, and we can treat them as exogenous. Once this stage is reached, DES should not have much impact on economic growth even though other measures of better nutrition may do. But for most developing countries, especially those which have been plagued with serious malnutrition problems; an increase in DES is most likely to increase population immediately and significantly. As a result, it should not be surprising to see a slow improvement of nutrition status and sluggish economic growth at the very beginning. Once this short run population effect is exhausted, the long run productivity effect will become the dominant force. This explains why the short run effect could be negative while the long run effect is positive.

Finally, what is the difference between SSA and ESEA that makes improvement in DES have positive impact only in the latter group? We believe the population effect also plays a major role. If we let population growth follow the trajectory shown in Figure 9, it may take a long time for a developing country to emerge from the nutrition-growth trap. However, if proper population control is also implemented with nutrition improvement plan, then the effect of the latter will be more prominent.

6. Conclusions and Policy Implications

Improvement of nutrition status in developing countries has multiple importances. First of all, better nutrition, which would lead to better health, is by itself a key indicator of a country's welfare. Second, healthier labor force is more productive, in both physical production and human capital production. Hence, better nutrition serves as a capacity building for human capital. This is a main driving force for improvement in standard of living. Finally, developed countries can also benefit directly from a more integrated and vibrant global economy.

Our empirical results lead to the following conclusions.

- Better nutrition is associated with faster economic growth in the long run. The magnitude of this effect, taken at the current sample mean, is about 0.5 percentage point for a 500 kcal/day increase in dietary energy supply.
- The short run effect, however, is rather ambiguous. It is not uncommon to observe a negative short run effect especially when the positive impact of nutrition on population growth is strong.
- In both the short run and the long run, we find evidence that nutrition's contribution to growth can be positive if population growth effect is properly controlled.
- Since nutrition contributes for the economic growth in the long run, any policies to improve nutritional status have to have a long-term provision. Corollary to this, a country, which implements this type of policies, must commit to it in the long run.
- Results show that having hanger in the country is costly in terms of economic growth in the short run as well as the long run.
- We find evidence that there are strong associations in both direction, i.e. nutrition on growth and growth on nutrition. However, both associations seem to show significantly lagged and asymmetric effects. This calls for further detailed modeling of the short run dynamics of both time series.

7. References

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8. Tables

Table 1a: DES and Long Run Economic Growth (1960-1999): OLS

Dependent Variable: Annual growth rate of GDP per capita, 1960-1999	(1)	(2)	(3)
Intercept	-0.0050	0.0142	0.0057
	(-0.34)	(0.97)	(0.33)
Log of initial GDP per capita	-0.0026	-0.0048	-0.0041
	(-1.59)	(-3.23)	(-2.22)
Initial DES	4.10e-6	6.35e-6	7.40e-6
	(0.74)	(1.28)	(1.55)
Investment Share	0.0019	0.0016	0.0016
	(5.72)	(5.13)	(4.94)
Population growth rate	-0.0051	-0.0028	-0.0035
	(-2.24)	(-1.51)	(-1.65)
Sub-Saharan Africa dummy		-0.0163	-0.0171
		(-3.75)	(-3.78)
Latin America and Caribbean dummy		-0.0088	-0.0108
		(-2.60)	(-2.23)
South Asia dummy		-0.0053	-0.0059
		(-1.29)	(-1.36)
Developing country dummy			0.0056
			(0.79)
Number of Observations:	87	87	87
Adjusted R^2:	0.48	0.55	0.55

Note: t-values in parentheses, calculated with White-Heteroscedasticity-Consistent standard error.

Table 1b: DES and Long Run Economic Growth (1960-1999): OLS

Dependent Variable: Annual growth rate of GDP per capita 1960-1999	(1) Developing Country	(2) Developed Country
Intercept	-0.0063	0.0598
	(-0.36)	(2.22)
Log of initial GDP per capita	-0.0030	-0.0040
	(-1.50)	(-1.26)
Initial DES	5.16e-6	-4.63e-6
	(0.78)	(-0.60)
Investment Share	0.0020	0.0008
	(5.36)	(1.63)
Population growth rate	-0.0053	-0.0043
	(-1.63)	(-1.54)
Number of Observations:	65	22
Adjusted R^2:	0.43	0.31

Note: t-values in parentheses, calculated with White-Heteroscedasticity-Consistent standard error. 114 countries total, 22 out of 27 developed countries and 65 out of 87 developing countries provide sufficient information for the estimation.

Table 1c: DES and Long Run Economic Growth (1960-1999): OLS

Dependent Variable: Annual growth rate of GDP per capita 1960-1999	(1) Sub-Saharan Africa	(2) Latin America and Caribbean	(3) East and South East Asia
Intercept	0.0011	-0.0014	0.0379
	(0.05)	(-0.03)	(3.41)
Log of initial GDP per capita	-0.0064	0.0002	-0.0054
	(-2.13)	(0.03)	(-2.19)
Initial DES	6.94e-6	3.07e-6	3.42e-5
	(1.04)	(0.31)	(4.19)
Investment Share	0.0021	0.0004	0.0009
	(4.57)	(0.57)	(2.05)
Population growth rate	-0.0039	-0.0015	-0.0274
	(-0.63)	(-0.33)	(-7.83)
Number of Observations:	26	21	7
Adjusted R^2:	0.48	-0.19	0.82

Note: t-values in parentheses, calculated with White-Heteroscedasticity-Consistent standard error. 26 out of 36 in SSA, 21 out of 21 in LAC, and 7 out of 11 ESEA provide sufficient information for the estimation.

Table 2a: DES and Medium Run Economic Growth (by decade): OLS

Dependent Variable: Annual growth rate of GDP per capita by decade	(1) Pooled	(2) 1960-1969	(3) 1970-1979	(4) 1980-1989	(5) 1990-1999
Intercept	0.0426	-0.0020	0.0354	0.0461	-0.0196
	(2.94)	(-0.08)	(1.40)	(1.98)	(-0.78)
Log of initial GDP per capita	-0.0017	-0.0010	-0.0060	-0.0021	-0.0008
	(-1.11)	(-0.24)	(-2.80)	(-0.88)	(-0.31)
Initial DES	-1.08e-5	6.77e-6	1.76e-6	-1.13e-5	4.11e-6
	(-2.45)	(0.69)	(0.22)	(-1.64)	(0.60)
Investment Share	0.0014	0.0011	0.0017	0.0016	0.0014
	(6.06)	(2.64)	(3.58)	(3.81)	(3.23)
Population growth rate	-0.0054	0.0034	-0.0015	-0.0126	-0.0017
	(-2.88)	(1.24)	(-0.46)	(-7.97)	(-0.57)
Sub-Saharan Africa	-0.0151	-0.0174	-0.0173	-0.0033	-0.0100
	(-3.72)	(-2.59)	(-2.46)	(-0.41)	(-1.45)
Latin America and Caribbean	-0.0096	-0.0159	-0.0054	-0.0155	0.0020
	(-2.82)	(-3.26)	(-0.84)	(-2.88)	(0.36)
South Asia	-0.0037	-0.0110	-0.0217	0.0106	-0.0161
	(-0.83)	(-1.27)	(-2.71)	(1.11)	(-2.16)
Number of Observations:	380	75	89	103	113
Adjusted R^2:	0.24	0.31	0.26	0.50	0.25

Note: t-values in parentheses, calculated with White-Heteroscedasticity-Consistent standard error. $F(8,348) = 14.86$, thus the null of constant coefficient across all four decades is rejected.

Table 2b: DES and Medium Run Economic Growth (by decade): LSDV, ITGMM, IT2SLS

Dependent Variable: Annual growth rate of GDP per capita by decade	(1) LSDV	(2) ITGMM	(3) IT2SLS
Log of initial GDP per capita	-0.0230	-0.0155	-0.0228
	(-4.97)	(-0.90)	(-1.37)
Initial DES	-9.73e-6	-4.00e-5	-4.00e-5
	(-1.76)	(-1.66)	(-1.66)
Investment Share	0.0016		
	(7.42)		
Population growth rate	-0.0067		
	(-2.43)		
Decade 70	-0.0002		
	(-0.06)		
Decade 80	-0.0100		
	(-2.96)		
Decade 90	-0.0065		
	(-1.81)		
Number of Observations:	380	181	181
Adjusted R^2:	0.70	0.11	0.15

Note: t-values in parentheses. Column 1: Null of no fixed effect is rejected with F(113,259) = 2.69. Random effect model is rejected with a Wald statistic (χ^2) equal to 22.67. Column 2: Over-identification restriction has χ^2 with degree of freedom equal to 2. P-value=0.41.

Table 2c: DES and Economic Growth (decade panel): OLS

Dependent Variable: Annual growth rate of GDP per capita 1960-1999, by decade	(1) Developing Country	(2) Developed Country
Intercept	0.0230	-0.0184
	(2.23)	(-0.46)
Log of initial GDP per capita	-0.0029	0.0038
	(-1.65)	(1.37)
Initial DES	3.50e-6	-5.06e-7
	(0.72)	(-0.06)
Investment Share	0.0017	0.0011
	(6.25)	(2.85)
Population growth rate	-0.0080	0.0013
	(-4.47)	(0.59)
Decade 70	-0.0044	-0.0194
	(-1.09)	(-3.73)
Decade 80	-0.0249	-0.0236
	(-6.65)	(-4.72)
Decade 90	-0.0201	-0.0284
	(-5.37)	(-4.44)
Number of Observations:	293	87
Adjusted R^2:	0.34	0.37

Note: t-values in parentheses, calculated with White-Heterscedasticity-Consistent standard error. 87 observations out of 108 (27x4) for developed countries, and 293 out of 348 (87x4) for developing countries provide sufficient information for the estimation.

Table 2d: DES and Economic Growth (decade panel): OLS

Dependent Variable: Annual growth rate of GDP per capita, by decade	(1) Sub-Saharan Africa	(2) Latin America and Caribbean	(3) East and South East Asia
Intercept	0.0167	-0.0125	-0.0255
	(0.78)	(-0.48)	(-0.72)
Log of initial GDP per capita	-0.0034	0.0029	-0.0074
	(-1.11)	(0.73)	(-1.92)
Initial DES	2.38e-7	6.53e-7	3.73e-5
	(0.03)	(0.09)	(3.27)
Investment Share	0.0016	0.0005	0.0016
	(4.06)	(1.27)	(2.58)
Population growth rate	-0.0029	-0.0004	-0.0003
	(-0.65)	(-0.14)	(-0.04)
Decade 70	-0.0050	0.0024	-0.0016
	(-0.79)	(0.41)	(-0.17)
Decade 80	-0.0186	-0.0295	-0.0159
	(-3.46)	(-6.20)	(-1.17)
Decade 90	-0.0226	-0.0091	-0.0292
	(-3.94)	(-1.86)	(-2.25)
Number of Observations:	120	82	32
Adjusted R^2:	0.28	0.32	0.29

Note: t-values in parentheses, calculated with White-Heterscedasticity-Consistent standard error. 120 observations out of 144 (=36x4) for SSA, 82 out of 84 (=21x4) for LAC, and 32 out of 44 (=11x4) for ESEA provide sufficient information for the estimation.

Table 3a: DES and GDP Growth Rate: The Quinquennial Case: Full Sample

Dependent Variable: 5-year average growth rate of GDP per capita	(1) OLS	(2) LSDV	(3) ITGMM
Intercept	0.0123		
	(0.92)		
Log Initial GDP per capita	-0.0013	-0.0222	-0.0132
	(-0.99)	(-4.93)	(-0.74)
Initial DES	1.81e-6	-9.56e-6	-2.00e-5
	(0.44)	(-1.66)	(-0.60)
Investment Share	0.0015	0.0019	0.0006
	(7.39)	(9.41)	(0.63)
Population Growth	-0.0044	0.0003	-0.0085
	(-3.38)	(0.21)	(-0.75)
1965-1969	-0.0035	0.0003	
	(-0.86)	(0.06)	
1970-1974	-0.0009	0.0056	
	(-0.20)	(1.31)	
1975-1979	-0.0157	-0.0070	
	(-3.39)	(-1.60)	
1980-1984	-0.0316	-0.0183	
	(-7.02)	(-4.07)	
1985-1989	-0.0200	-0.0048	
	(-4.67)	(-1.08)	
1990-1994	-0.0277	-0.0120	
	(-5.69)	(-2.60)	
1995-1999	-0.0171	-0.0004	
	(-3.95)	(-0.08)	
SSA	-0.0031		
	(-0.72)		
LAC	-0.0016		
	(-0.48)		
SA	0.0093		
	(1.82)		
ESEA	0.0155		
	(3.60)		
Number of Observations:	757	114 x 8	528
Adjusted R^2:	0.28	0.50	0.02

Note: t-value in parenthesis. Column 1 t-values are calculated with White-Heteroscedasticity-Consistent standard error. Total number of countries is 114. Column 2 no-fixed-effect is rejected with $F(113,632) = 2.63$ (p-value < 0.0001). Column (3) over-identification condition has $\chi^2(1)$ equal to 2.05.

Table 3b: DES and GDP Growth Rate: The Quinquennial Case: By Country Group

Dependent Variable: 5-year average growth rate of GDP per capita	(1) SSA	(2) LAC	(3) ESEA
Intercept	-0.0087	-0.0215	-0.0396
	(-0.36)	(-0.88)	(-1.04)
Log Initial GDP per capita	-0.0030	0.0046	-0.0046
	(-0.98)	(1.12)	(-1.27)
Initial DES	2.69e-6	-3.47e-6	3.47e-5
	(0.30)	(-0.45)	(2.49)
Investment Share	0.0016	0.0009	0.0012
	(4.82)	(2.38)	(2.45)
Population Growth	0.0043	0.0005	0.0001
	(0.79)	(0.18)	(0.02)
1965-1969	-0.0013	-0.0054	0.0107
	(-0.16)	(-1.00)	(0.86)
1970-1974	0.0059	0.0066	0.0102
	(0.66)	(0.90)	(0.79)
1975-1979	-0.0202	-0.0086	0.0048
	(-2.08)	(-1.01)	(0.36)
1980-1984	-0.0323	-0.0383	-0.0096
	(-3.47)	(-6.12)	(-0.58)
1985-1989	-0.0131	-0.0241	-0.0052
	(-1.54)	(-3.23)	(-0.34)
1990-1994	-0.0392	-0.0095	-0.0117
	(-4.33)	(-1.34)	(-0.63)
1995-1999	-0.0107	-0.0134	-0.0250
	(-1.26)	(-2.03)	(-1.55)
Number of Observations:	238	164	66
(number of countries)	(36)	(21)	(11)
Adjusted R^2:	0.25	0.24	0.20

Note: t-value in parenthesis. Column 1 t-values are calculated with White-Heteroscedasticity-Consistent standard error. Total number of countries is 114. Column 2 no-fixed-effect is rejected with F(113,632) = 2.63 (p-value < 0.0001).

Table 4: Granger Causality Test: Seemingly Unrelated Regression (SUR)

Dependent Variable	Growth Rate of Real GDP Per Capita (y)	Log DES (des)
Intercept	-0.0677	0.1025
	(-2.01)	(4.67)
y_{-1}	0.2494	0.0485
	(14.20)	(4.24)
y_{-2}	0.0428	-0.0032
	(2.38)	(-0.27)
y_{-3}	0.0880	0.0136
	(4.99)	(1.18)
y_{-4}	0.0157	0.0120
	(0.91)	(1.07)
y_{-5}	0.0439	0.0092
	(2.76)	(0.89)
des_{-1}	0.0296	0.8659
	(1.10)	(49.33)
des_{-2}	-0.0385	0.0681
	(-1.09)	(2.95)
des_{-3}	0.0033	0.0729
	(0.09)	(3.19)
des_{-4}	-0.0024	0.0103
	(-0.07)	(0.45)
des_{-5}	0.0177	-0.0300
	(0.67)	(-1.75)
F-Test:		
coefficients of y lags = 0		19.44
(p-value)		(0.000)
coefficients of des lags = 0	4.98	
(p-value)	(0.026)	
Adjusted R^2 (OLS):	0.10	0.97
Cross Correlation:	0.22	
Number of Observations:	3386	

Note: t-value in parenthesis.

Table 5a: Growth without Agriculture Sector

Dependent Variable: Growth Rate of Real Non-Agricultural GDP Per Capita	(1) 1960-1999 (OLS)	(2) by decade (OLS)	(3) by decade (LSDV)
Intercept	0.0248	0.0652	
	(0.92)	(3.43)	
Log of initial GDP	-0.0081	-0.0041	-0.0385
	(-3.97)	(-2.49)	(-6.44)
Initial DES	1.00e-5	-5.25e-6	-1.00e-5
	(1.43)	(-0.95)	(-1.51)
Investment share	0.0020	0.0018	0.0019
	(4.85)	(5.54)	(5.85)
Population growth	-0.0022	-0.0082	-0.0105
	(-0.48)	(-4.56)	(-2.44)
SSA	-0.0182	-0.0101	
	(-2.96)	(-1.84)	
LAC	-0.0095	-0.0063	
	(-1.71)	(-1.53)	
SA	-0.0096	0.0014	
	(-1.60)	(0.20)	
Decade 70		-0.0109	0.0057
		(-1.83)	(1.09)
Decade 80		-0.0298	-0.0020
		(-5.27)	(-0.34)
Decade 90		-0.0293	0.0004
		(-4.88)	(0.06)
Number of Observations:	42	311	109
Adjusted R^2:	0.53	0.30	0.70

Note: t-values in parenthesis, calculated with White-Heteroscedasticity-Consistent standard error. Total number of countries is 114.

Table 5b: Growth without Agriculture Sector

Dependent Variable: Annual growth rate of Non-Agriculture GDP per capita, by decade	(1) Sub-Saharan Africa	(2) Latin America and Caribbean	(3) East and South East Asia
Intercept	0.0631	0.0374	-0.0330
	(2.10)	(1.14)	(-0.60)
Log of initial GDP per capita	-0.0081	0.0006	-0.0120
	(-2.06)	(0.13)	(-2.73)
Initial DES	-3.99e-6	-5.82e-6	5.24e-5
	(-0.32)	(-0.66)	(2.74)
Investment Share	0.0022	0.0004	0.0013
	(3.82)	(0.79)	(1.57)
Population growth rate	-0.0023	-0.0043	0.0022
	(-0.33)	(-1.28)	(0.22)
Decade 70	-0.0253	0.0013	0.0091
	(-2.14)	(0.18)	(0.52)
Decade 80	-0.0394	-0.0305	-0.0059
	(-3.67)	(-5.30)	(-0.31)
Decade 90	-0.0474	-0.0122	-0.0223
	(-4.00)	(-2.19)	(-1.15)
Number of Observations:	110	70	30
Adjusted R^2:	0.28	0.25	0.13

Note: t-values in parentheses, calculated with White-Heterscedasticity-Consistent standard error. 110 observations out of 144 (=36x4) for SSA, 70 out of 84 (=21x4) for LAC, and 30 out of 44 (=11x4) for ESEA provide sufficient information for the estimation.

Table 6a: DES Orthogonal to Agriculture GDP

Dependent Variable: average annual growth rate of GDP per capita	(1) 1960-1999 (OLS)	(2) by decade (OLS)	(3) by decade (LSDV)
Intercept	0.0277	0.0365	
	(1.54)	(2.64)	
Initial GDP	-0.0048	-0.0033	-0.0286
	(-3.66)	(-2.57)	(-5.63)
Initial DES (residual)	1.15e-5	-6.53e-6	-7.58e-6
	(1.85)	(-1.61)	(-1.32)
Investment share	0.0018	0.0016	0.0016
	(4.39)	(6.08)	(6.55)
Population growth	-0.0026	-0.0069	-0.0061
	(-0.95)	(-4.31)	(-1.88)
SSA	-0.0184	-0.0091	
	(-3.54)	(-2.12)	
LAC	-0.0108	-0.0054	
	(-2.23)	(-1.66)	
SA	-0.0077	0.0006	
	(-1.55)	(0.13)	
Dec70		-0.0056	0.0032
		(-1.36)	(0.80)
Dec80		-0.0231	-0.0083
		(-5.97)	(-1.92)
Dec90		-0.0205	-0.0041
		(-5.34)	(-0.90)
Number of Observations:	42	311	109
Adjusted R^2:	0.58	0.36	0.73

Note: t-values in parenthesis, calculated with White-Heteroscedasticity-Consistent standard error (column 1 and 2 only).

Column 1 first step result is:

$$DES = \underset{(39.71)}{1946} + \underset{(2.95)}{0.2188} * yagr - \underset{(-1.15)}{1.168e\text{-}5} * yagr^2$$

Adjusted $R^2 = 0.51$. "yagr" stands for real agriculture GDP per capita.

Column 2 and 3 first step result is:

$$DES = \underset{(94.19)}{2204} + \underset{(10.36)}{0.1181} * yagr - \underset{(5.98)}{2.95e\text{-}6} * yagr^2$$

Adjusted $R^2 = 0.51$.

Column 3 F-test for the null of no fixed effect is equal to 2.39 (p-value < 0.0001).

Table 6b: DES Orthogonal to Agriculture GDP

Dependent Variable: Annual growth rate of GDP per capita, by decade	(1) Sub-Saharan Africa	(2) Latin America and Caribbean	(3) East and South East Asia
Intercept	0.0199	0.0085	0.0311
	(0.90)	(0.24)	(0.94)
Log of initial GDP per capita	-0.0029	0.0010	-0.0011
	(-0.97)	(0.26)	(-0.40)
Initial DES	3.36e-7	-7.96e-7	2.76e-5
	(0.04)	(-0.04)	(2.74)
Investment Share	0.0016	0.0006	0.0014
	(3.86)	(1.30)	(1.94)
Population growth rate	-0.0032	-0.0029	-0.0055
	(-0.69)	(-0.92)	(-0.86)
Decade 70	-0.0100	0.0034	0.0004
	(-1.30)	(0.54)	(0.04)
Decade 80	-0.0238	-0.0282	-0.0118
	(-3.45)	(-5.14)	(-0.81)
Decade 90	-0.0276	-0.0096	-0.0242
	(-3.85)	(-1.85)	(-1.73)
Number of Observations:	110	70	30
Adjusted R^2:	0.29	0.28	0.22

Note: t-values in parentheses, calculated with White-Heteroscedasticity-Consistent standard error. 110 observations out of 144 (=36x4) for SSA, 70 out of 84 (=21x4) for LAC, and 30 out of 44 (=11x4) for ESEA provide sufficient information for the estimation.

Table 7: Simultaneous Equations: Maximum Likelihood Estimation

	(1)	(2)	(3)
Growth Equation			
Constant	1.9263	1.9176	1.9257
	(1.05)	(31.8)	(0.46)
Investment Share	0.1969	0.1962	0.1975
	(15.72)	(18.30)	(15.83)
Population Growth	-0.1324		-0.1385
	(1.51)		(1.63)
Lag(t) Log DES	-0.6142	-0.6452	-0.6143
	(2.57)	(20.23)	(1.14)
Log DES Equation			
Constant	7.8344	7.8345	7.8308
	(2056.28)	(2061.71)	(2007.90)
Lag(t) growth rate	0.0049	0.0048	0.0074
	(6.93)	(6.86)	(8.60)
σ_g	1.59	1.59	1.59
	(117.08)	(120.20)	(113.57)
σ_d	-1.65	-1.64	-1.65
	(-121.18)	(-124.49)	(-165.00)
ρ_{gd}	0.0513	0.0689	0.0500
	(2.07)	(3.74)	(1.67)
τ_g	2	2	2
τ_d	5	5	4
Number of Observations:	2717	2717	2717
Mean Log Likelihood:	-0.9403	-0.9408	-0.9357

Note: t-value in parenthesis. Growth rate is multiplied by 100 to facilitate numerical calculation (same reason for taking logarithm of DES). Moreover, in order to bound the variances and correlation coefficient, we use exponential function to transform the standard deviations and (exp(x)-exp(-x))/(exp(x)+exp(-x)) to transform the correlation coefficient function. The purpose is to bound standard deviation above zero, and correlation coefficient within (-1,1). Thus for column (1) the standard deviations and correlation coefficients are (4.90, 0.19, 0.05). For column (2) they are (4.90, 0.19, 0.07), and for column (3) they are (4.90, 0.19, 0.05).

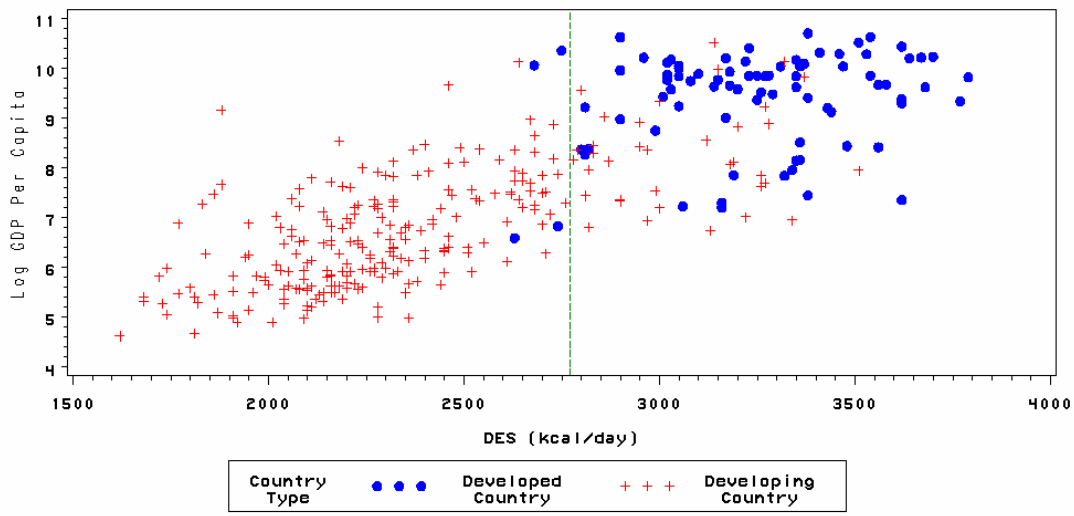
Table 8: Developing Countries in Nutrition Trap: by group

Country Group	1960-1969	1970-1979	1980-1989	1990-1999
Sub-Saharan Africa (36)	12	8	7	12
Latin America and the Caribbean (21)	7	4	0	2
East and Southeast Asia (11)	6	2	1	1

Note: For 1990-1999, 12 SSA countries are AGO, BDI, CAF, ETH, GHA, GIN, KEN, MOZ, MWI, RWA, SLE, and TCD. 2 LAC countries are HTI and PER. 1 ESEA country is KHM.

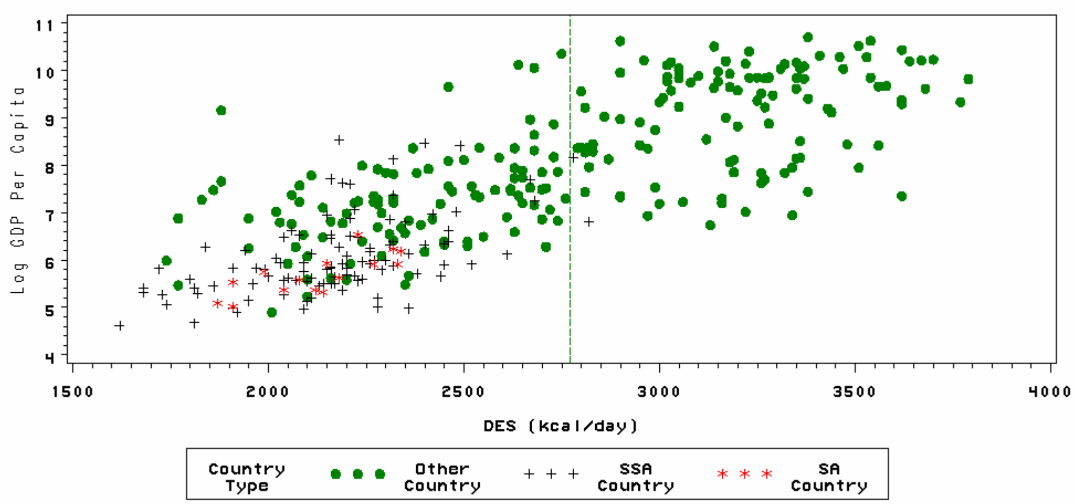
9. Figures

Figure 1: Log GDP Per Capita and DES Per Capita (kcal/day)



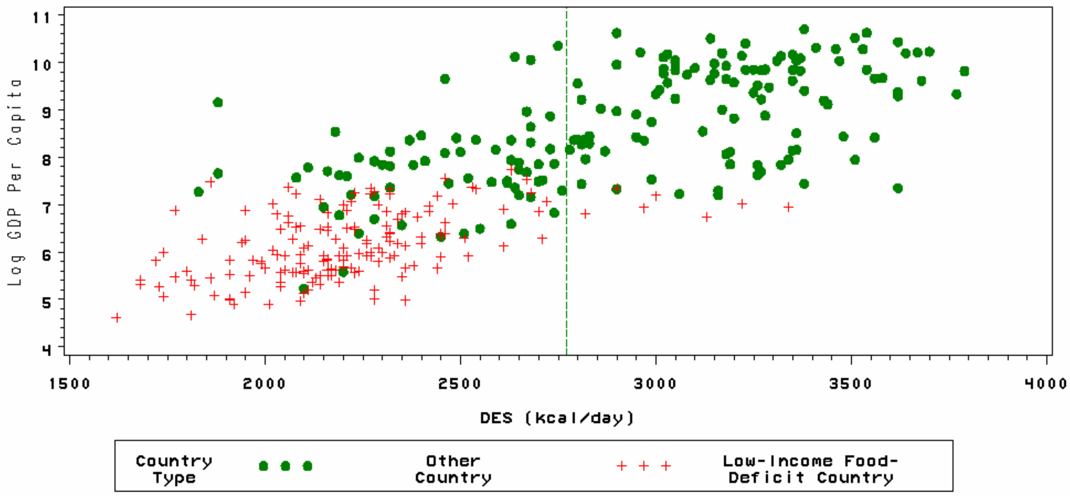
Note: 129 (countries) x 3 (decades) = 387 observations.
Reference Line = Target DES (2770 kcal/day).

Figure 1a: Log GDP Per Capita and DES Per Capita (kcal/day)
(With SSA and SA Countries Highlighted)



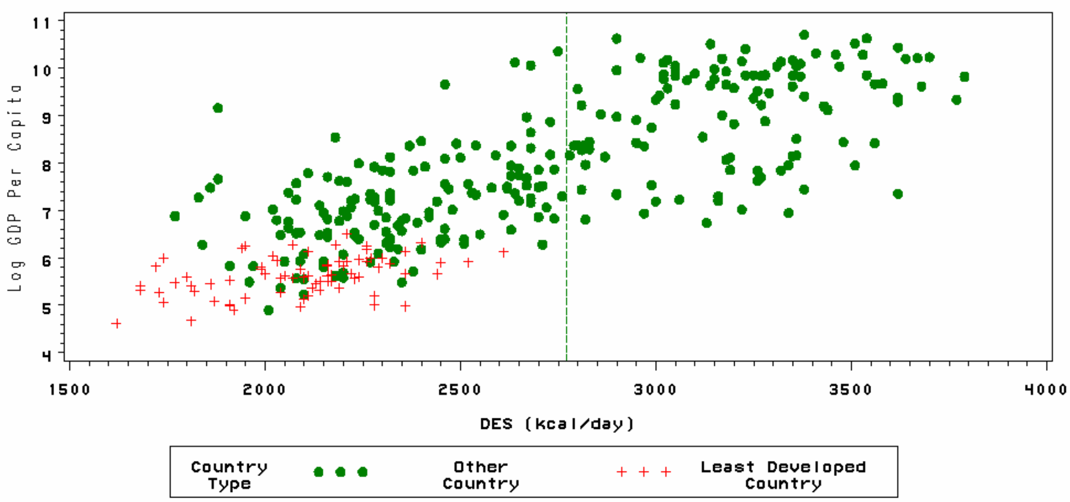
Note: 129 (countries) x 3 (decades) = 387 observations.
Reference Line = Target DES (2770 kcal/day).

Figure 1b: Log GDP Per Capita and DES Per Capita (kcal/day)
(With LIFDC Countries Highlighted)



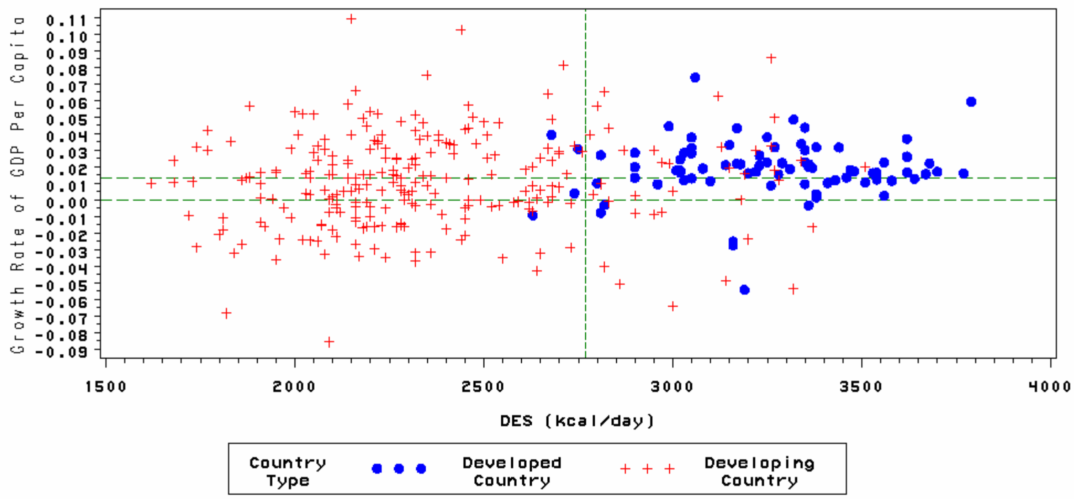
Note: 129 (countries) x 3 (decades) = 387 observations.
Reference Line = Target DES (2770 kcal/day).

Figure 1c: Log GDP Per Capita and DES Per Capita (kcal/day)
(With LDC Countries Highlighted)



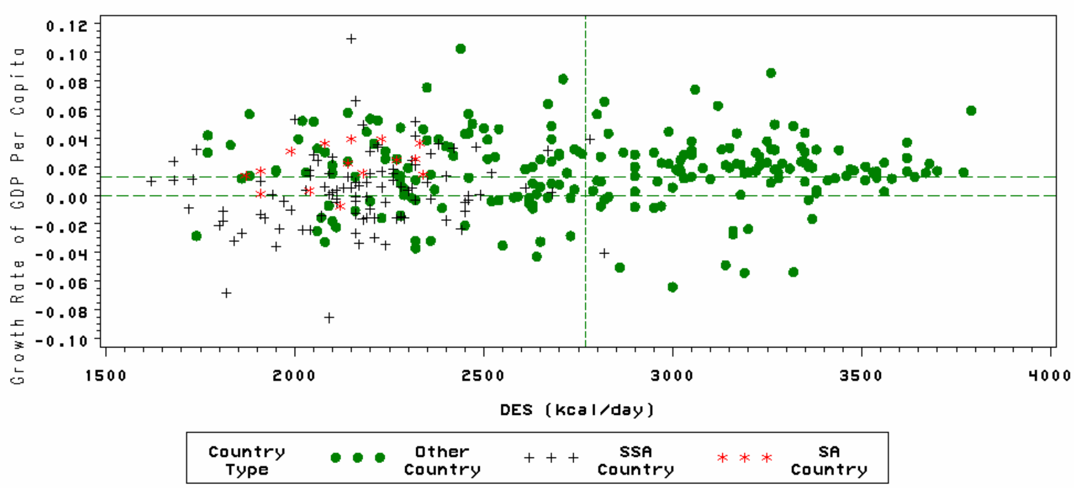
Note: 129 (countries) x 3 (decades) = 387 observations.
Reference Line = Target DES (2770 kcal/day).

Figure 2: Growth Rate of GDP Per Capita and DES Per Capita(kcal/day)



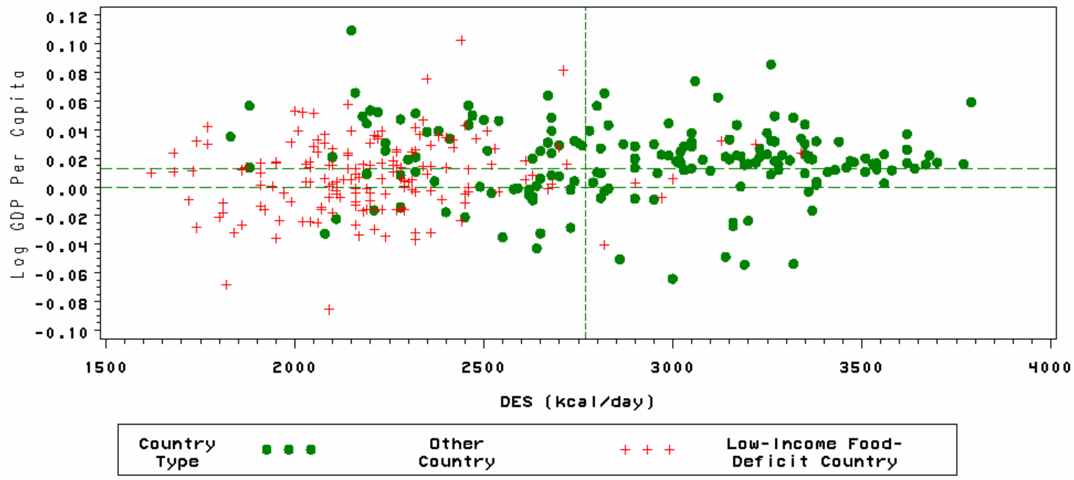
Note: 129 (countries) x 3 (decades) = 387 observations.
Reference Lines = Horizontal: Zero and Mean Growth Rate (0.013).
Vertical: Target DES (2770 kcal/day).

Figure 2a: Growth Rate of GDP Per Capita and DES Per Capita (kcal/day)
(With SSA and SA Countries Highlighted)



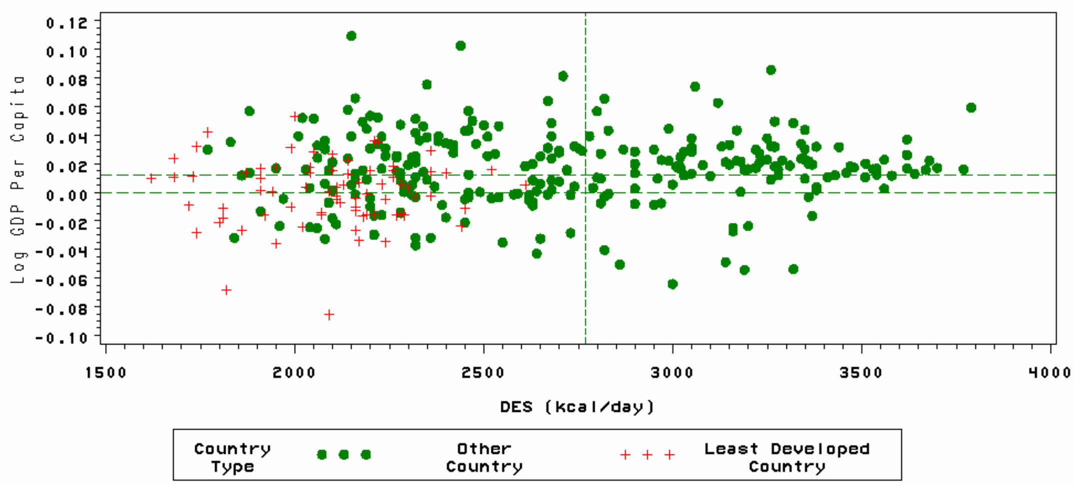
Note: 129 (countries) x 3 (decades) = 387 observations.
Reference Lines = Horizontal: Zero and Mean Growth Rate (0.013).
Vertical: Targe DES (2770 kcal/day).

Figure 2b: Growth Rate of GDP Per Capita and DES Per Capita (kcal/day)
(With LIFDC Countries Highlighted)



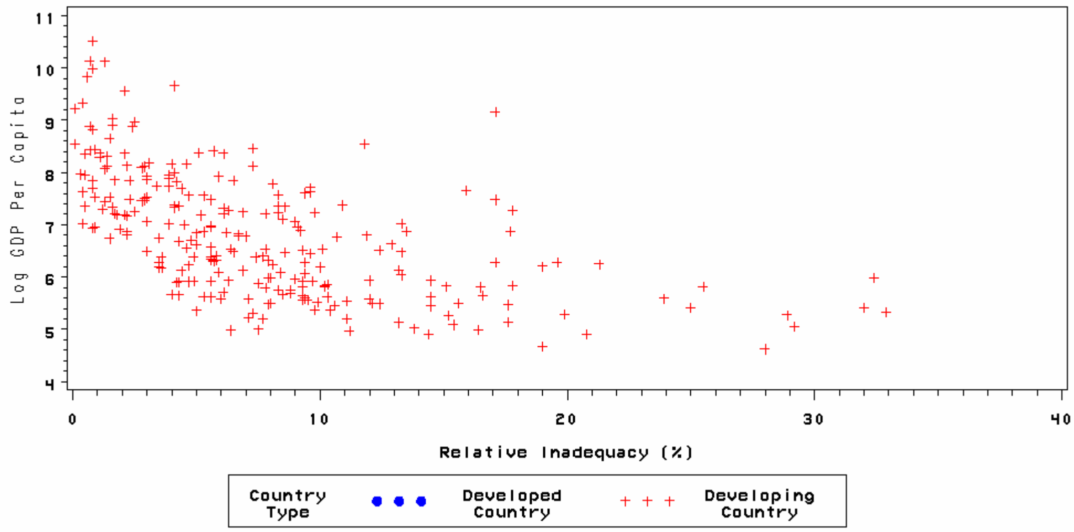
Note: 129 (countries) x 3 (decades) = 387 observations.
Reference Lines = Horizontal: Zero and Mean Growth Rate (0.013).
Vertical: Target DES (2770 kcal/day).

Figure 2c: Growth Rate of GDP Per Capita and DES Per Capita (kcal/day)
(With LDC Countries Highlighted)



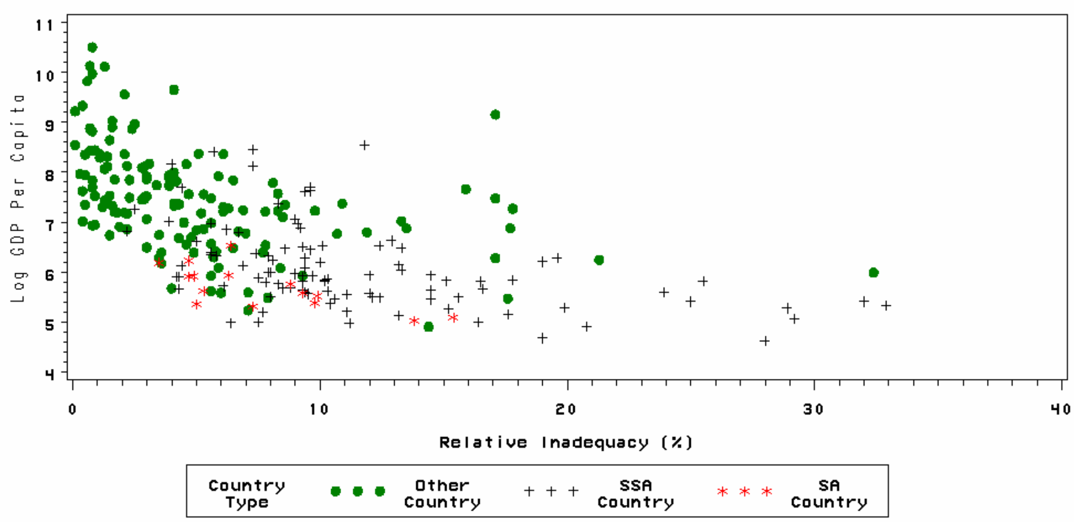
Note: 129 (countries) x 3 (decades) = 387 observations.
Reference Lines = Horizontal: Zero and Mean Growth Rate (0.012).
Vertical: Target DES (2770 kcal/day).

Figure 3: Log GDP Per Capita and Relative Inadequacy (%)



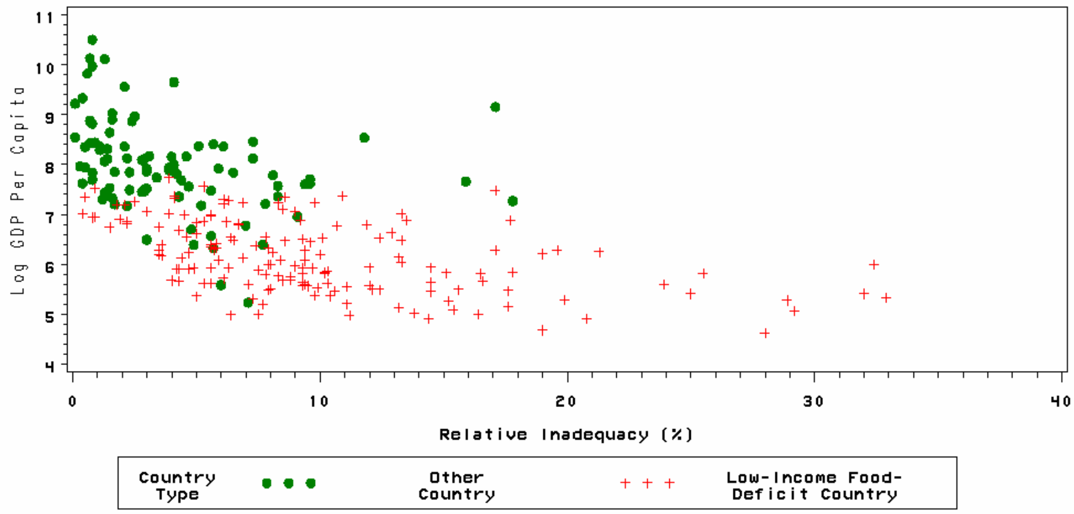
Note: 129 (countries) x 3 (decades) = 387 observations.

Figure 3a: Log GDP Per Capita and Relative Inadequacy (%)
(With SSA and SA Countries Highlighted)



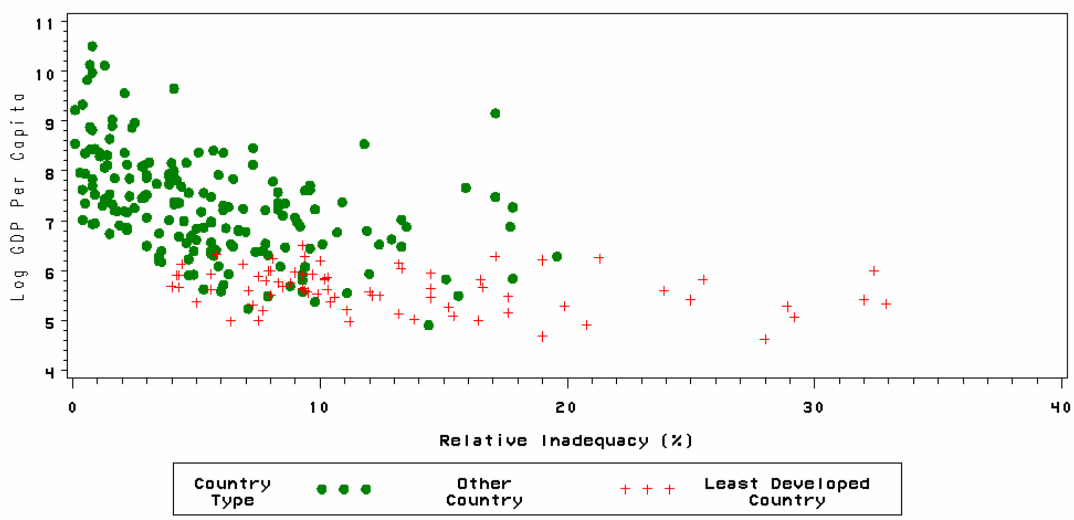
Note: 129 (countries) x 3 (decades) = 387 observations.

Figure 3b: Log GDP Per Capita and Relative Inadequacy (%)
(With LIFDC Countries Highlighted)



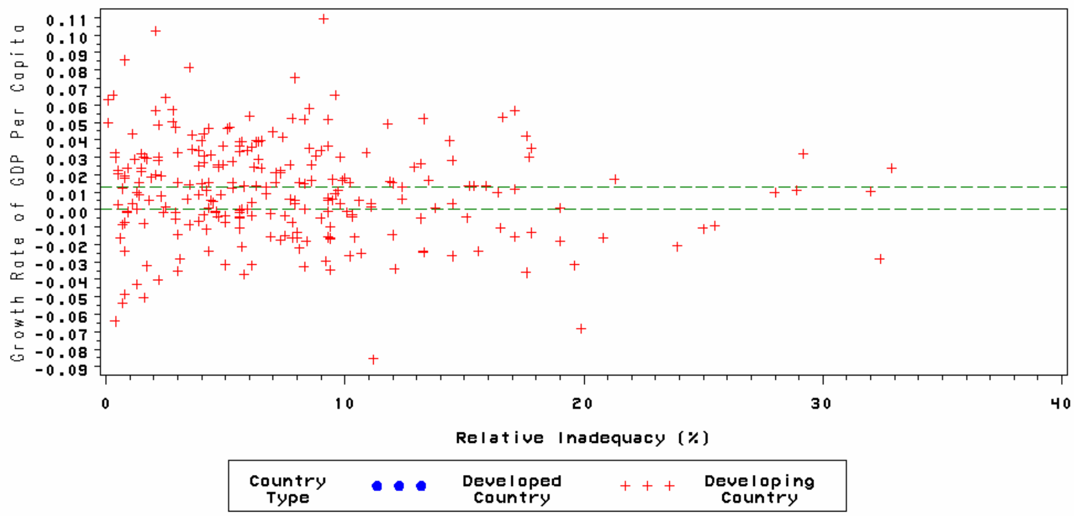
Note: 129 (countries) x 3 (decades) = 387 observations.

Figure 3c: Log GDP Per Capita and Relative Inadequacy (%)
(With LDC Countries Highlighted)



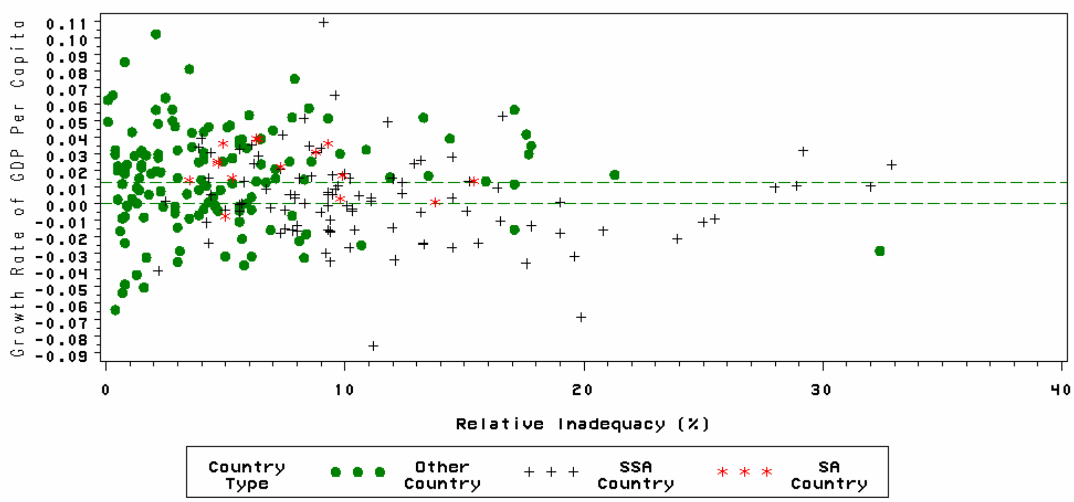
Note: 129 (countries) x 3 (decades) = 387 observations.

Figure 4: Growth Rate of GDP Per Capita and Relative Inadequacy (%)



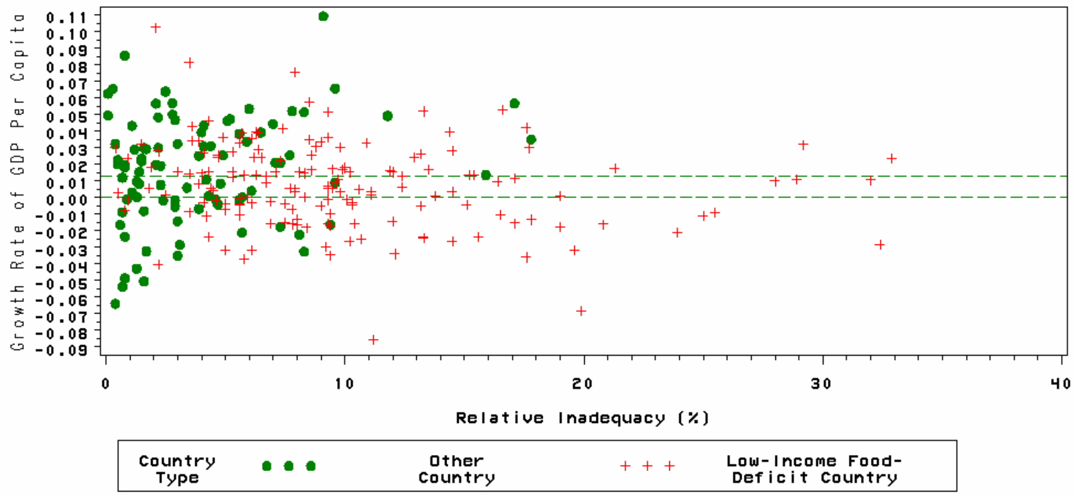
Note: 129 (countries) x 3 (decades) = 387 observations.
Reference Lines = Zero and Mean Growth Rate (0.013).

Figure 4a: Growth Rate of GDP Per Capita and Relative Inadequacy (%)
(With SSA and SA Countries Highlighted)



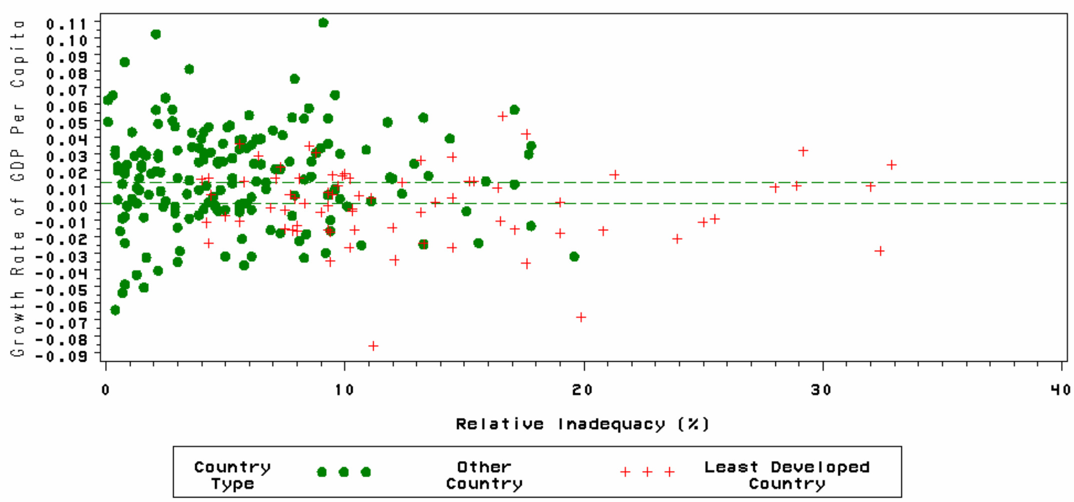
Note: 129 (countries) x 3 (decades) = 387 observations.
Reference Lines = Zero and Mean Growth Rate (0.013).

Figure 4b: Growth Rate of GDP Per Capita and Relative Inadequacy (%)
(With LIFDC Countries Highlighted)



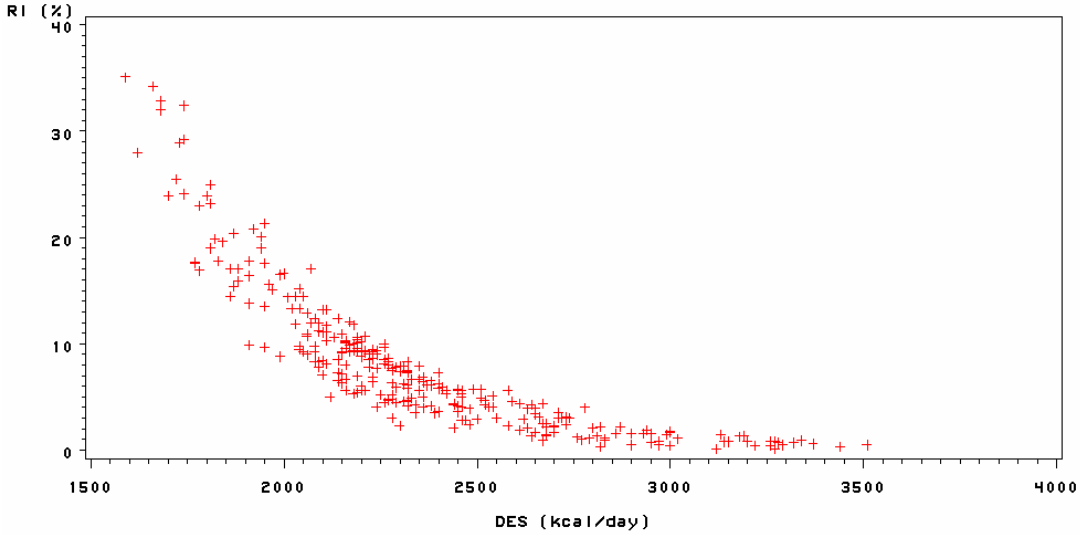
Note: 129 (countries) x 3 (decades) = 387 observations.
Reference Lines = Zero and Mean Growth Rate (0.013).

Figure 4c: Growth Rate of GDP Per Capita and Relative Inadequacy (%)
(With LDC Countries Highlighted)



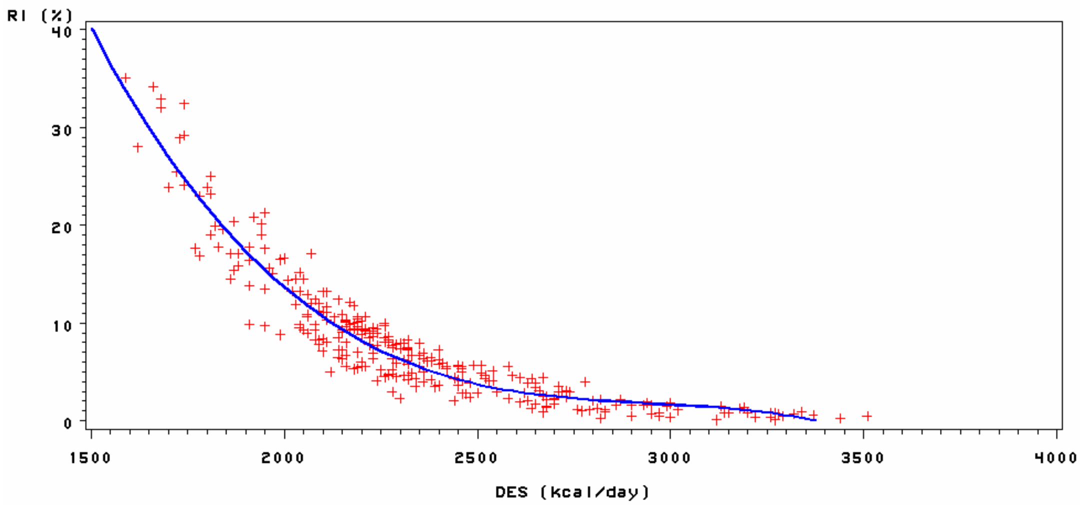
Note: 129 (countries) x 3 (decades) = 387 observations.
Reference Lines = Zero and Mean Growth Rate (0.013).

Figure 5: Relative Inadequacy and Daily Energy Supply



Note: 129 (countries) x 3 (decades) = 387 observations.

Figure 5: Relative Inadequacy and Daily Energy Supply



Regression Equation:
RI = 306.0588 - 0.305422*DES + 0.000103*DES^2 - 1.163E-8*DES^3
Note: 129 (countries) x 3 (decades) = 387 observations.

Figure 6: DES Disbritution by Decade

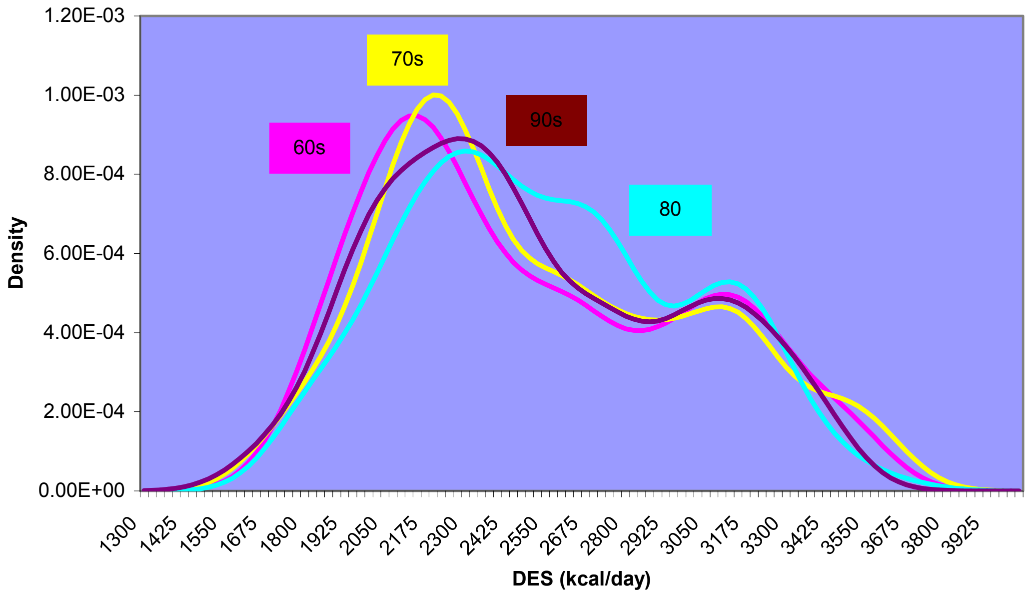


Figure 7: Sample Correlation of Log DES and Growth

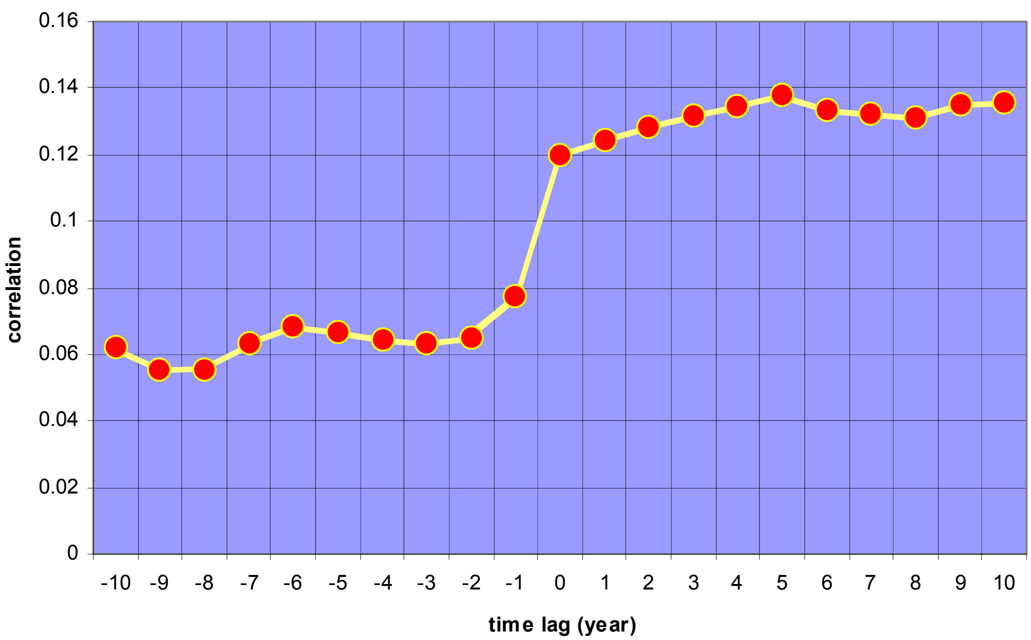


Figure 8: Log Likelihood

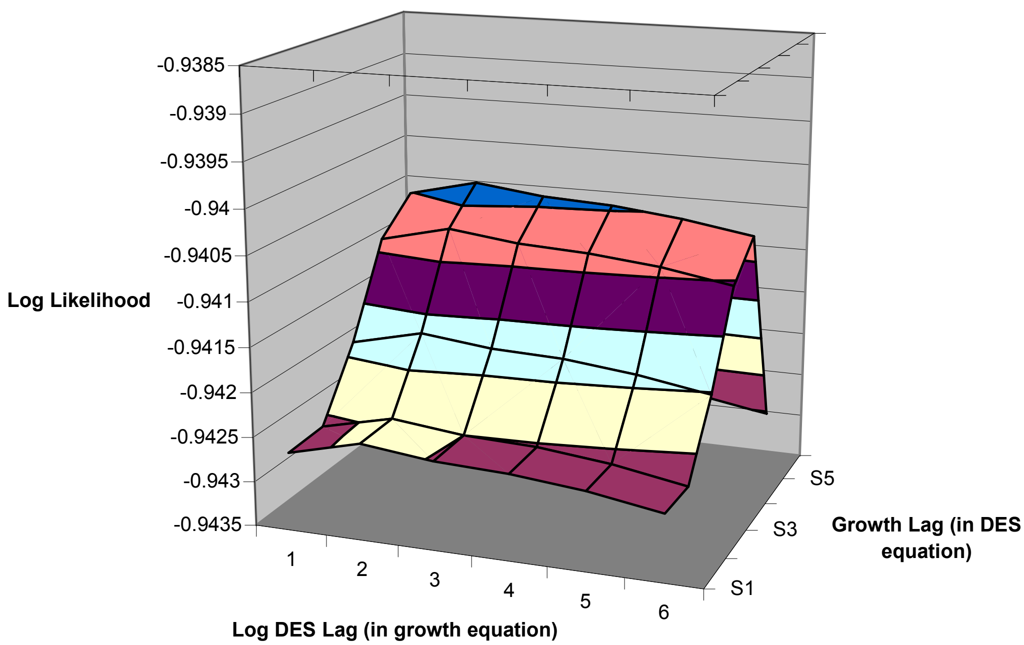


Figure 9: DES and Population Growth

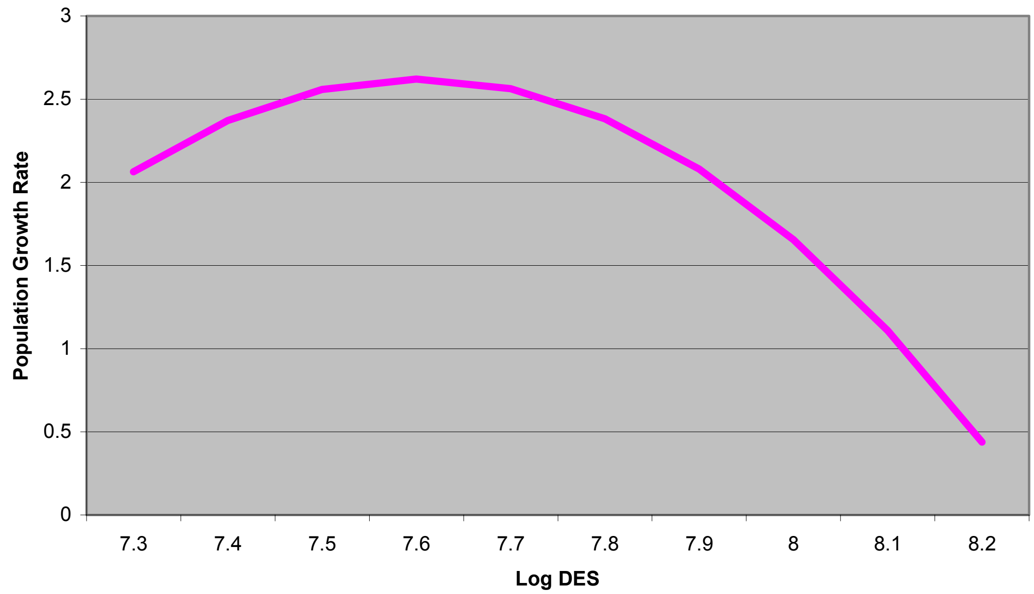


Figure 10: DES and Population Growth