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MODELLING THE ROLE OF HEALTH STATUS IN THE TRANSITION OUT OF MALTHUSIAN EQUILIBRIUM

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Abstract This paper develops a two periods, overlapping generations model of economic growth in order to analyse the mechanisms through which health status has contributed to the Transition out of Malthusian Times. Health affects the accumulation of human capital both directly and indirectly, through its effects on the learning capacity of children and on the survival probability from childhood to adulthood. An extremely poor level of child health might determine that the threshold level of adult income that allows for child education was too high to be reached. In this situation, a minimum health status, for any given adult income, is necessary for the investment in education to be worthwhile. Hence, the achievement of a minimum level of physical status emerges as a necessary condition for the development of intellectual human capital and it determines a permanent change in the slope of the growth path.

Keywords Health Human Capital, Transition, Economic Growth

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1. Introduction

This paper analyses the temporal evolution of health status, human capital and income. In particular, it focuses on the importance of health for the Transition out of the Malthusian regime. Improved health status has been considered a key factor for the Transition in both the theories of the Epidemiologic Transition (Omran [1971], Arora [2005]) and that of the Techno-Physio Evolution (Fogel [2004]). Fogel (2004.), for instance, concluded that the raise in the amount of available energy and improved physical status accounts for about 50 percent of British economic growth since 1790. Arora (2001), investigating the growth path of 10 industrialized countries over 100 to 120 years, provides further historical evidence of the importance of health for economic growth. According to this analysis, health increased the pace of growth of the considered countries by 30 to 40 percent, altering permanently the slope of the growth path.

In models of transition, the central role is given to education while improved health is usually seen as a by-product of economic growth.[1] Arora (2005) demonstrates, however, that income has weak power in explaining the improvement in health that characterizes the Transition. Factors other than income levels may explain the permanent change in levels of health status, such as the discovery of vaccines or behavioural changes.

The analysis presented in this paper uses a framework similar to Galor and Wail (2000) but leaves the relationship between technological progress and population size aside, and includes the consideration of health status and its effects on the accumulation of human capital. This methodology was considered appropriate to highlight the mechanisms through which health status has permanently changed the growth path of developed economies. At the outset, low levels of human capital and poor health status characterize the economy. The level of consumption scarcely exceeds the baseline maintenance; population growth is determined by the combination of high fertility rates and short life spans. Technology is roughly constant at a low level. The ultimate source of growth in this phase of stagnation is the development of physical human capital, which is expected to improve thanks to non-economic waves of health-related innovations. Improved health, however, does not result in the permanent escape from the Malthusian pseudo-equilibrium of stagnation, but it only shifts up the equilibrium levels of income and health status. In addition, the slow and non-continuous improvement of human capital does not initially affect the fertility rate. In other words, the poor health status and low life expectancy that characterize the Malthusian regime coexist with a constant and high

[1] See, for instance, Lucas (2002) and Galor and Weil (1999,2000).

fertility rate. This is primarily due to the benefit of parenthood, which induces adults to rear the maximum feasible number of children. In fact, it is argued that when adults' possibility of generating income is very low, children can work and contribute to the family budget. Subsequent increases in the differential between parental and child labour will then progressively decrease the benefit of child labour. The resultant dynamic of participation of children to family income is similar to Hazan and Berdugo (2002).

In time, the increase in income generated by improved health results in a level of consumption, which has positive effects on physical status, and reverse causation subsequently emerges. Health-induced periods of expansion becomes larger thanks to the effect of double causation between health and income. However, the passage to a regime of modern growth occurs when human capital approaches a level at which, rises in per capita income are devoted to augmenting personal consumption as well as to subtract time of child labour in favour of education. The achievement of this threshold level mostly depends on the improvement in health status. In fact, health not only has a direct effect on human capital and contributes this way to the progressive increase of income, but it is a key factor in determining the outcomes of education, too. As shown by Pollit et al. (1993), Haas et al. (1996), Alderman et al. (2001), the Micronutrient Initiative and United Nations Children's Fund (2004), and Miguel (2005), among others, improved health status raises the learning capacity of children and, thus, it affects returns to education. Hence, growth in health status stimulates families to invest in child quality, which in turn gives rise to the development of intellectual human capital. Moreover, health status affects life expectancy and, therefore, the expected value of lifetime earnings and the benefit of education. Improved health status emerges thus as a precondition for the development of intellectual human capital and the consequent shift to a regime of Modern Growth.

The rest of the paper is organized as follows. Section 2 presents the economy and the results of the maximization problem that emerges from the model. An analysis of the production system and technological progress in section 3 provides the means for assessing the evolution of income and to highlight the importance of health in the Transition to the Modern Growth regime. The last section summarizes the main conclusions.

2. Model Economy

The economy is characterized by two overlapping generations of adults and children. At each period *t* a new generation is born, each individual having only one parent. In the early stages of their lives, children spend the available unit of time (minus a fraction φ that represents infancy) accumulating human capital and/or working, in accordance with the decision of the parent. The technology of production of human capital is assumed to be

$$h_{t+1} = \log[\lambda_t (e_{t+1} + \varphi) + \vartheta],^{2} \tag{1}$$

where human capital is measured in efficiency units of labour and $0 \le e_{t+1} \le 1 - \varphi$ represents time dedicated to schooling; $\vartheta > 1$ is a sufficient condition for the existence of a minimum positive level of child human capital, regardless of education. It is assumed that λ_t, where $0 < \lambda_t = \lambda(P_t) < 1$, $\lambda'(P_t) > 0$ and $\lambda''(P_t) < 0$, is a function of physical status at time *t*, P_t. Consequently, physical status affects the production of efficiency units of labour even in absence of education, by increasing the efficiency of informal learning during infancy. P_t is supposed to be a positive function of per capita consumption above the baseline maintenance level bm, and other health-related non-economic exogenous factors, x_t,

$$P_t = P\left(N \equiv \max\left[\frac{c_t}{1 + n_{t+1}} - bm; 0 \right]; x_t \right),^{3} \tag{2}$$

when c_t represents family present consumption, n_{t+1} the number of children for a given parent ($1 + n_{t+1}$ thus represents the total family size, since children have only one parent), and $\partial P_t / \partial N > 0, \partial^2 P_t / \partial N^2 < 0$. Baseline maintenance is the sum of the energy needed to

[2] This is a modified version of the human capital function used by Berti Ceroni (2001).

[3] It is assumed that *P'*(·) > 0 and *P''*(·) < 0. Beherman and Deolalikar (1988) and Strauss and Thomas (1995) suggest that increases in certain measures of nutritional status may be associated with reductions in welfare beyond a certain point. As a consequence, *P'*(·) might be negative when over consumption negatively affects physical status. However, this has no effect on our conclusions.

keep vital organs functioning when the body is at rest, plus the energy needed to eat and digest food and for vital hygiene. Dietary energy available for other activities is a residual.

With reference to child labour, it is assumed that children do not directly participate in the labour market. In other words, during the fraction of childhood that is not dedicated to schooling, children contribute to family income by obtaining a fixed quantity of consumption commodity per unit of time, k. The rationale behind this assumption is that children are expected to recollect food or doing other extra-market activities rather than directly participate in the production. Another interpretation that is compatible is that children are systematically exploited and are consequently paid a fixed quantity of consumption commodity. This assumption, though formally simpler, generates an effect similar to Hazan and Berdugo (2002), in that the differential between child and parental labour tends to increase with time and this leads to the progressive reduction of child labour.

Children face a probability of surviving to adulthood $s_t < 1$, which is assumed to be a positive function of health status, with decreasing returns. In the second period of life, adults optimally choose the number of children n_{t+1}, the time they will dedicate to schooling e_{t+1} and family consumption c_t. Parents face a time-cost of rearing a child φ (related to infancy). It can be observed that the cost of bringing up a child, regardless of education, is expressed as time subtracted to work and is thus a positive function of the level of human capital of the parent. During this very first stage of life children start accumulating human capital, as follows from (1). The cost of education does not depend on adult human capital. It is in fact assumed that the only cost related to schooling is the opportunity cost of bringing up a student rather than a worker. Moreover, to rear a child could even increase family budget, when the contribution of children to family income is greater than the cost of child care. The choice of an adult i, endowed with a level of human capital h_t, is thus subject to the budget constraint

$$h_t w_t (1 - n_{t+1}\varphi) + k n_{t+1}(1 - \varphi - e_{t+1}) = c_t \,. \tag{3}$$

Hence, family present consumption depends both on adult and children income. The wage per efficiency unit of labour, w_t, varies as time passes. However, it is assumed that firms fix it at the beginning of each period, and adults take the wage as given in the maximization problem. Preferences of adults born at $t - 1$ are represented by the utility function

$$U_t = \alpha \cdot [\log(c_t)] + \beta \cdot [\log(n_{t+1})] + \gamma \cdot s_t^E \cdot [h_{t+1}], \qquad (4)$$

where it is assumed that $\beta > \gamma \cdot s_t^E$; the preference for child quantity is greater than the preference for child quality. $0 < s_t^E = s_{t-1} \leq 1$ is the expected probability of survival from childhood to adulthood. Consequently, the preference for child human capital is conditioned by the expected probability that the accumulation of efficiency units of labour will generate benefits in the following period. It should be noted that s_t^E is taken as given by parents. A more appropriate approach would consider s_t as a stochastic function of health status, allowing for the modelling of outbreaks and famines. However, this does not change the main conclusions if it is assumed that its trend depends primarily on individual health status. Another assumption that is considered in order to simplify the analysis, is that parents take into account an expected value of the returns to education, $\lambda_t^E = \lambda_{t-1}$ in (1), while the real value that emerges from the decisions about consumption affects the evolution of human capital of the following generations.

The logical phases of the maximization problem can be described as follows. The firm fixes the wage per efficiency unit of labour at the beginning of the period. Parents, given the levels observed in the previous period, formulate expectations about the survival probability of their children and the returns to education. Given these expectations, the wage and their level of human capital, adults choose the number of children, the time that they will dedicate to schooling and family consumption. These decisions will then affect the health status of children, their level of human capital and the real evolution of population size, dependent on the survival probability. The firm will finally consider these values to fix the wage of the following period, and the process continues *ad infinitum*.

2.1 Utility Maximization

Adults choose c_t, n_{t+1} and e_{t+1} to maximize (4) subject to (3) and (1). Results implied by the first order conditions of the maximization problem will be presented following the order of decreasing adult human capital and income.

It is initially assumed that

$$h_t w_t \equiv z_t^P \geq \frac{\beta k(\vartheta + \lambda_t^E)}{s_t^E \gamma \lambda_t^E \varphi} \equiv \tilde{z} \tag{5}$$

holds, where z_t^P is parents' income. In this situation, the optimal levels of the choice variables are

$$n_{t+1} = \frac{\beta}{(\alpha + \beta)\varphi} \equiv n_{MIN}, \tag{6a}$$

$$e_{t+1} = 1 - \varphi, \tag{6b}$$

$$pcc_t \equiv \frac{c_t}{1 + n_{t+1}} = \frac{z_t^P \varphi \alpha}{\beta + (\alpha + \beta)\varphi}, \tag{6c}$$

where pcc_t represents per capita consumption at *t*.

Proposition **P1**: If adult income is greater than the threshold level $\tilde{z}$, children dedicate the whole available time to education. Moreover, the fertility rate in this situation is the minimum fertility rate of the economy.

It should be noted that dedicating the whole childhood to education does not ensure the achievement of the maximum level of human capital. This depends on health status as well, and on the effects of health status on the cognitive capacity of children. If health status can improve, then human capital is not at its maximum.
When

$$\hat{z} \equiv \frac{k(\beta(\vartheta + \lambda_t^E \varphi) + s_t^E \gamma \lambda_t^E (1 - \varphi))}{s_t^E \gamma \lambda_t^E \varphi} \leq z_t^P < \tilde{z}, \tag{7}$$

an interior solution exists, and first order conditions of the maximization problem imply

$$n_{t+1} = \frac{z_t^P (\beta - \gamma s_t^E) \lambda_t^E}{(\alpha + \beta)(z_t^P \lambda_t^E \varphi - k(\vartheta + \lambda_t^E)}, \tag{8a}$$

$$e_{t+1} = \frac{z_t^P s_t^E \gamma \lambda_t^E \varphi - k(\vartheta\beta + s_t^E \gamma \lambda_t^E (1-\varphi) + \beta \lambda_t^E \varphi)}{h_{MIN}(\beta - \gamma s_t^E)\lambda_t^E}, \tag{8b}$$

$$pcc_t = \frac{z_t^P \alpha (z_t^P \varphi \lambda_t^E - k(\vartheta + \lambda_t^E)}{z_t^P \lambda_t^E (\beta - \gamma s_t^E + (\alpha+\beta)\varphi) - k(\alpha+\beta)(\vartheta + \lambda_t^E)}. \tag{8c}$$

Both time dedicated to education and per capita consumption are increasing functions of adult income ($\partial e_{t+1} / \partial z_t^P > 0; \partial pcc_t / \partial z_t^P > 0$). However, their values are lower than those obtained in the previous situation. In fact,

$$\frac{z_t^P s_t^E \gamma \lambda_t^E \varphi - k(\vartheta\beta + s_t^E \gamma \lambda_t^E (1-\varphi) + \beta \lambda_t^E \varphi)}{h_{MIN}(\beta - \gamma s_t^E)\lambda_t^E} < 1 - \varphi$$

$$\Leftrightarrow \frac{k\beta(\vartheta + \lambda_t^E) - s_t^E z_t^P \gamma \lambda_t^E \varphi}{k\lambda_t^E (s_t^E \gamma - \beta)} < 0,$$

which is true when $\beta > s_t^E \gamma \cup z_t^P < \tilde{z},$ which are conditions that hold in this situation.

Proposition **P2**: If adult income varies between the threshold levels $\hat{z}$ and $\tilde{z}$, parents choose that their children have to allocate their available time between work and education. Time dedicated to education is an increasing function of adult income.

It should be noted that the threshold level of income $\hat{z}$ plays a central role in the analysis, since it is the minimum adult income that allows for investments in education. In other words, if adult income is below this threshold, parents choose that their children have to dedicate the whole first period of their life (excluding infancy) to work for contributing to the family budget. The threshold level $\hat{z}$ is a function of child health status, though indirectly via λ_t^E and s_t^E. In particular, if health status is so poor that $\lambda_t^E \to 0$ and/or $s_t^E \to 0,$ then $\lim_{\lambda_t^E (s_t^E) \to 0} \hat{z} = +\infty.$ In other words, it would be necessary an infinite income for adults to choose to school their children. The following corollary to Proposition 2 summarizes this result.

Corollary **C1**: An extremely poor level of child health might determine that the minimum requirement of adult income to school children was too high to be reached. In this situation, a minimum health status, for any given adult income, is necessary for the investment in education to be worthwhile.

This corollary provides a rationale for the existence of a minimum health requirement for the investment in education, as assumed, among others, by Galor and Mayer-Foulkes (2004).

It is now considered the situation in which adult human capital and income are at a level that makes optimal to let children work during the whole childhood,

$$\breve{z} \equiv \frac{(1-\varphi)}{\varphi} k \leq z_t^P < \hat{z}. \tag{9}$$

It should be noted that, since φ is reasonably lower than one half, this condition states that adult income has to be greater than $(1-\varphi)/\varphi$ times the amount of consumption commodity that children are able to obtain from extra-market activities.[4] If adult income is at a level for which (9) holds, two consequences emerge. First, as mentioned above, parents choose not to school their children. Second, a level of income greater than this threshold implies that to rear a child is a costly activity. In other words, if adult income is below the threshold $\breve{z}$, having children increases family and per capita consumption. If it is assumed that (9) holds, the solution of the maximization problem is characterized by

$$n_{t+1} = \frac{z_t^P \beta}{(\alpha+\beta)(z_t^P \varphi - k(1-\varphi))} \tag{10a}$$

$$e_{t+1} = 0, \tag{10b}$$

$$pcc_t = \frac{z_t^P (z_t^P \varphi - k(1-\varphi))}{z_t^P (\beta + (\alpha+\beta)\varphi) - k(\alpha+\beta)(1-\varphi)}. \tag{10c}$$

[4] De La Croix and Doepke (2003), for instance, set φ = 0.075 in their calibration in a similar framework.

Proposition **P3**: If adult income varies between the threshold levels $\check{z}$ and $\hat{z}$, parents choose that their children should dedicate their available time to work. The fertility rate is still a decreasing function of adult income.

It should be noted that $\lim_{z_t \to \check{z}} n_{t+1} = \infty \Rightarrow \lim_{z_t \to \check{z}} pcc_t = 0.$ The rationale behind this result is that as bringing up children tends to be a costless (or even profitable) activity, parents choose to have as many children as they can. However, it is supposed that there is a biological constraint, n_{MAX}, that represents the maximum number of children that a woman can physically have during adulthood. As a consequence, since fertility increases as the wage decreases, there is a threshold level of adult income, $\acute{z}$, where $\check{z} \leq \acute{z} < \hat{z}$, for which the maximum fertility rate is reached. Under this assumption, condition (9) has to be modified substituting the threshold $\check{z}$ for $\acute{z}$.

When it is finally assumed that

$$z_t^P \leq \acute{z}, \tag{11}$$

the maximization problem is solved for

$$n_{t+1} = n_{MAX}, \tag{12a}$$

$$e_{t+1} = 0, \tag{12b}$$

$$pcc_t = \frac{(z_t^P + kn_{MAX})(1-\varphi)}{1+n_{MAX}}. \tag{12c}$$

Proposition **P4**: If adult income is so poor that to rear a child increases family consumption, then adults choose to have the maximum feasible number of children. Moreover, individuals do not receive education and they dedicate the whole childhood (minus infancy) to work.

The dynamic of per capita consumption is extremely important in order to understand the Transition out of the Malthusian Era. As follows from (6c), (8c), (10c) and (12c), per capita consumption is a positive function of adult income. In the interval (0, $\acute{z}$], per capita consumption increases with adult income because the fertility rate remains constant at its maximum level. For higher values of adult income, the reduction in the number of children per family contributes to the growth of per capita consumption. Moreover, the lower fertility rate fully compensates the loss due to the reduction in child labour when children start attending school. As a result, children of parents endowed with higher levels of human capital always benefit from higher levels of per capita consumption.

A first result of the model is summarized in the human capital transition function

$$h_{t+1} = G(h_t) = \log(\lambda_t^E (e_{t+1} + \varphi) + \theta), \tag{13}$$

which represents the human capital of children as a function of the level of human capital of parents, when the wage per efficiency unit of labour is assumed to be constant. The value of e_{t+1} depends on adult income, as follows from the solution of the maximization problem. Moreover, since physical status improves while per capita consumption increases, λ_t^E is a function of adult income, too. Given that (13), if

$$\log(\lambda_t^E \varphi + \vartheta) < \hat{z} < Z, \tag{14}$$

the transition function provides one unstable and two stable steady states, as depicted in Figure 1.[5] In the shape of the transition function depicted in Figure 1, though variable depending on the value of parameters, four distinct states can be identified. The first, left-side horizontal segment corresponds to the situation in which children do not dedicate any time to education and consumption is below the baseline maintenance level, so that increased consumption has no significant effect on health status and learning capacities. It should be noted that this situation is only theoretical. In fact, a level of consumption below the baseline maintenance would not permit the survival of individuals in the shot-medium run. However, Fogel (2004) explains that variations in body size could have been the main mechanism through which malnourished populations achieved the equilibrium with the food supply. In Fogel's words, *varying body size was a universal way that the chronically malnourished populations of Europe responded to food constraints* (Fogel [2004], pag. 17). Hence, the baseline maintenance level could be a function of the physical status itself. If this is the case, and assuming that the economy is initially in equilibrium with the food supply by an adaptation of the body size, increasing levels of consumption always results in improved health status. This motivates the interpretation of the first horizontal segment as a theoretical boundary situation.

[5] See Appendix A.

The curve that follows represents the interval in which family income is still not sufficient enough to allow for investment in education; however, the level of consumption begins to determine improvements in health status that have consequences in terms of productive human capital. The shape of the transition function changes once more when the level of income stimulate parents to school their children. Finally, the last horizontal segment correspond to a situation in which individuals dedicate all their childhood to education and are endowed with the best physical status.

Given the transition function, a level of human capital greater than the threshold $h*$ in the graphical exercise of Figure 1, allows for a level of time dedicated to schooling that determines the convergence to the upper equilibrium level.

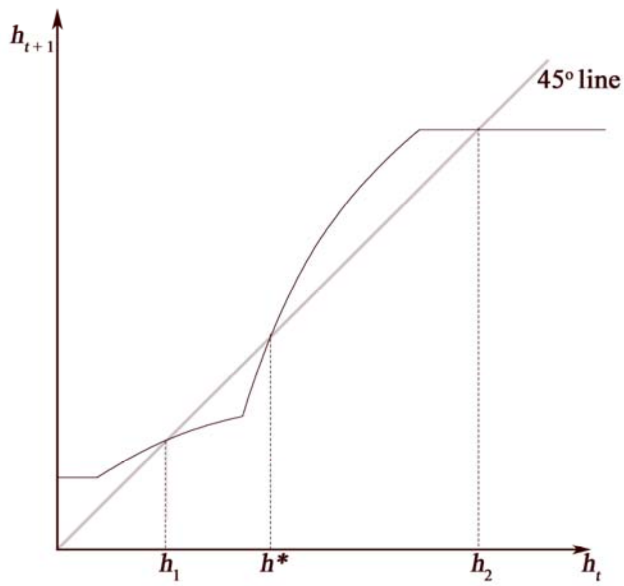

Figure 1: Human capital transition function (w constant).

Given (13) subject to (14), it can be stated that

Proposition **P5**: If the wage per efficiency unit of labour is assumed to be constant, there is a threshold level of adult income that discriminates dynasties that converge to an upper equilibrium level of high human capital, from dynasties that converge to a steady-state equilibrium characterized by high fertility, unfavourable health status and low levels of human capital.

It should be noted that the wage per efficiency unit of labour has been supposed to be constant. The result obtained under this hypothesis is useful in order to understand phenomena like the club convergence in human capital levels depending on the initial distribution of human capital. However, on considering the historical evolution of the human population, and the phase of Malthusian Stagnation, it would be rational to suppose that every individual within an economy is initially endowed with a very low level of human capital. Hence, the economy is locked into a poverty trap at its genesis. Analysing the production system of the economy, and the effects of waves of innovations related to health, is used as a means of modelling the escape from the Malthusian Era.

3 Production and temporal evolution of income levels

Human capital is assumed to be the only factor of production. The output at t is produced according to

$$Y_t = A_t H_t \, , \tag{15}$$

where H_t is the quantity of efficiency units of labour at t and $A_t > 0$ represents the level of technology at t.
Where $h_t = H_t/L_t$ represents the number of efficiency units of labour per worker, the income per worker is equal to

$$z_t^P \equiv h_t w_t = A h_t \, . \tag{16}$$

Technological progress depends on the temporal evolution of human capital,

$$g_t = g(\dot{h} \equiv \frac{\partial h}{\partial t}) \, , \tag{17}$$

where $\partial g / \partial \dot{h} > 0$, $\partial^2 g / \partial \dot{h}^2 < 0$ and $0 < g_t < 1$. The main idea behind this assumption is that if human capital does not increase, the population can only maintain the technological level already achieved. In order to generate an increase in the growth rate of technology, improved capacities are needed. This simple dynamic of g_t appears to be consistent with the historical evidence and with the acceleration in the rate of technological change after 1700, especially after 1900 (Fogel [2004]).

The key factor in determining economic growth is the increase in the level of human capital. Since Malthusian Times are characterized by the absence of investment in education, the ultimate source of growth during this phase is the improvement of health status.

The level of income depends on the wage per efficiency unit of labour and on the level of human capital of workers. Depending on the temporal evolution of these variables, income can increase or decrease. The dynamic of income can be analysed through the transition function

$$\begin{aligned} z_{t+1}^{P} &= A_{t+1} h_{t+1} = A_t (1+g_t) \log\left[\lambda_t (e_{t+1} + \phi) + \vartheta\right] = \\ &= z_t^{P} (1+g_t) \frac{h_{t+1}}{h_t} \end{aligned} \quad (18)$$

where both g_t and h_{t+1} are functions of previous levels of human capital and income.

It is assumed that, initially, the economy is stuck in a long-term equilibrium of Stagnation, corresponding to a situation like the lower steady-state in the example of Figure 1. In this situation, every individual is endowed with the minimum equilibrium level of human capital, and per capita consumption is at a level at which physical status mostly depends on exogenous factors. Moreover, children dedicate their time to contribute to family income and, in this initial situation of stable levels of human capital, technological progress is null by (17).

Proposition **P6**: Constant and very poor levels of human capital characterize Malthusian Times. This determines the absence of technological progress and results in stagnant levels of income. Economic factors by themselves can not explain the escape from this steady-state equilibrium of stagnation.

Since low levels of consumption and quasi-absent technological progress characterize pre-industrial times, it should be considered that income does not play a key role in explaining the transition. This conclusion is consistent with Arora (2001, 2005).

3.1 Effects of improved health status

It is now assumed that at time *t*, when the economy is assumed to be in a steady state equilibrium of Stagnation, an innovation that can improve health status is introduced. Physical status is thus assumed to improve by the exogenous increase of x_t in (2). Improved health results in an increase of learning capacities, returns to education λ_t, and, thus, of human capital and income at $t + 1$. It should be noted that technological progress determines a multiplicative effect of improved health. In fact, since human capital improves from t to $t + 1$, g_{t+1} results to be positive, as follows from (17). Hence, income increases from $t + 1$ to $t + 2$ as a consequence of technological progress. Three situation could emerge.

First, if

$$\frac{\partial P_t}{\partial x_t} > 0 \Rightarrow \left[\Delta h_{t+1} > 0, \Delta g_{t+1} > 0\right] \Rightarrow \Delta z_{t+2}^P > 0 \mid z_{t+3}^P \leq \breve{z}, \tag{19}$$

improved physical conditions determine an increase in the level of income (the notation $\Delta X = X_{t+1} - X_t$, where X is a generic variable, represents the increment between periods). However, the new level is not sufficient to generate further effects on human capital; technological progress turns out to be null in the third period, and income does not further increase. The economy comes back to a stationary situation, though characterized by a better health status and higher income. It should be noted that, as discussed in the previous section, this situation is only theoretical. By assuming that the population is initially in equilibrium with the food supply, an increase in consumption always results in improved physical status and human capital. This leads to the consideration of the second situation.

It is now considered that increasing family income generates a raise in per capita consumption that affects physical status, that is, a consumption level that is above the baseline maintenance,

$$\frac{\partial P_t}{\partial x_t} > 0 \Rightarrow \left[\Delta h_{t+1} > 0, \Delta g_{t+1} > 0\right] \Rightarrow \Delta z_{t+2}^P > 0 \mid z_{t+3}^P > \breve{z}. \tag{20}$$

The multiplication effect results to be larger in this situation. This is due to the backward effect of income on health. Improved health human capital in the first period will be followed by increasing income and technological progress. This, on turn, generates a further increase in physical status and improved human capital, and so on. However, decreasing returns determine that human capital, technological progress and income will cease to increase and the economy will approach a new equilibrium . Hence, if

$$\begin{aligned}
&\frac{\partial P_t}{\partial x_t} \Rightarrow \left[\Delta h_{t+1} > 0, \Delta g_{t+1} > 0\right] \Rightarrow \Delta z_{t+2}^{P} > 0 \Rightarrow 0 < \Delta P_{t+2} < \Delta P_{t+1} \\
&\Rightarrow \left[0 < \Delta h_{t+2} < \Delta h_{t+1}, 0 < \Delta g_{t+2} < \Delta g_{t+1}\right] \\
&\Rightarrow \ldots \\
&\Rightarrow (h_{t+N-1} = h_{t+N}; g_{t+N-1} = g_{t+N}) \mid z_{t+N-1}^{P} = z_{t+N}^{P} \le \hat{z},
\end{aligned} \tag{21}$$

the following proposition can be stated.

Proposition **P7**: Innovations that improve health status result in waves of economic expansion. However, while this shifts up the pseudo-equilibrium of Stagnation, it does not necessary and permanently change the growth path of the economy.

In other words, if the interactions across improved health human capital, technology and income do not result in a level of human capital that is above the threshold level $\hat{z}$, adults do not invest in child education, and human capital does not further increase. Hence, improved health status do not determine the take-off of economies.

It should be noted that, when adult income is below the threshold level $\acute{z}$, fertility rates remain constant. As a consequence, improved health status generates an increase in the growth rate of population through the augmented survival probability from childhood to adulthood. This is consistent with "Malthusian" population growth. When the level of income is above $\acute{z}$, the effect on population turns out to be uncertain; increasing survival probabilities coexist with progressively lower fertility rates.

The improvement of physical status generates further effects that allow for the investment in intellectual human capital. The increase in cognitive capacities and the enlargement of life spans act as incentives for the investment in child quality. While income slowly grows thanks to non-economic health-related innovations, the threshold level of income to invest in education becomes more and more accessible; this follows from

$$\frac{\partial \hat{z}}{\partial P_t} = -\frac{1}{(s_t)^2 \gamma \lambda_t^2 \varphi}\left[k\beta(\lambda_t(\vartheta + \lambda_t\varphi)\frac{\partial s_t}{\partial P_t} + s_t \vartheta \frac{\partial \lambda_t}{\partial P_t}\right], \tag{22}$$

which is negative because both the survival probability and returns to education depend positively on physical status. In absence of improvements in physical status, increasing income would not force the transition (see Corollary C1). It should be noted, however, that the model predicts that while improved health status is the ultimate source of growth during Stagnation, this generates increases in income and reverse causation subsequently emerges.[6] The third situation that could emerge as a consequence of one or subsequent waves of health-related innovations, is concerned with the achievement of an income level that allows for the investment in education. If

$$\begin{aligned}&\frac{\partial P_t}{\partial x_t} \Rightarrow \Delta z_{t+2}^P > 0 \Rightarrow \Delta P_{t+2} > 0 \Rightarrow \Delta \lambda_{t+2}^E > 0 \Rightarrow [\Delta \hat{z} < 0] \\ &\Rightarrow \Delta z_{t+3}^P > 0 \Rightarrow \ldots \Rightarrow z_{t+N-1}^P = z_{t+N}^P > \hat{z}(\lambda_{t+N}^E)\end{aligned} \tag{23}$$

holds, the synergies across health status, learning capacities of children (and incentives to the investment in education), technology and income, result in further improvements in the level of human capital through education. Improved intellectual human capital marks the passage to the Modern regime of growth.

Proposition **P8**: The transition out of the Malthusian Era is lead by improvements in physical status. The achievement of a minimum level of health is a necessary condition for the development of intellectual human capital. The moment at which children begin to allocate time to education marks the permanent change in the growth path of the economy.

[6] See Currais and Rivera (1999) for evidence supporting the hypothesis of reverse causation.

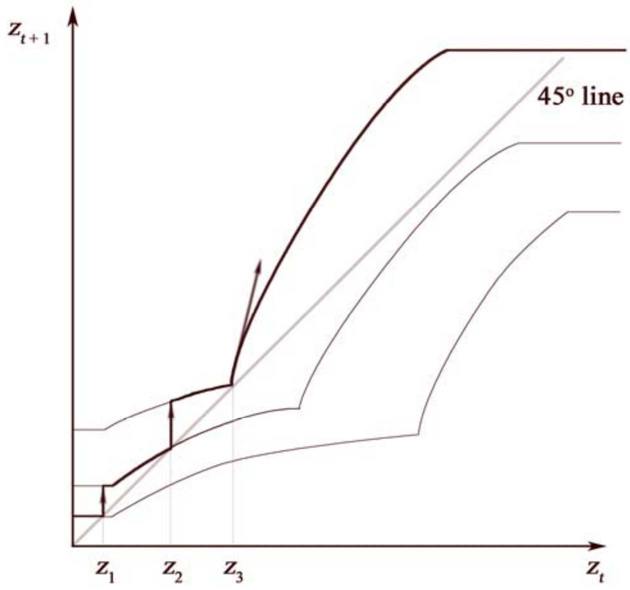

Figure 2: Evolution of adult income (the black line represents the transition function.)

Figure 2 provides a graphical example of the evolution of income. During the Malthusian Era, growth results from health-induced waves of economic expansion. Periods of expansion depends on the interactions between health human capital and technology. However, before the achievement of a minimum health status, improved health by itself does not determine a change in the growth path of the economy. It is the human-induced development of intellectual human capital, though made possible by improved health, the factor that determines the passage to the Modern Growth regime.

4 CONCLUSIONS

This paper develops a two periods, overlapping generation model in order to underlie the importance of health status in the Transition out of Malthusian Stagnation. Health-related innovations during the first stage of development and, subsequently, increases in the level of nutrition, stimulated a progressive, time-consuming improvement in physical status. This generates three distinct effects that have been considered in the model. First, it directly results in improved human capital. Second, it indirectly affects human capital by increasing the cognitive capacity of children and their aptitude to learn. Third, it rises returns to the investment in education through its influence on life spans and, consequently, on lifetime earnings.

The first phase of development is characterized by the absence of technological progress, high fertility rates and poor health status. The last factor impedes the investment in child quality constraining returns to education to a very low level. Therefore, children dedicate their available time to extra-market activities in order to contribute to the family budget. Improvements in health status during this phase generate waves of technological growth and increasing income. These periods of expansion are amplified by the double causation between health and income. However, this does not alter the evolution of the economy. In other words, improved health results in a shift of the steady-state (pseudo)-equilibrium of Malthusian Stagnation.

As health status improves, another effect emerges. Larger life spans and greater learning capacity of children increase the likelihood of investment in child quality. Health status emerges as a pre-condition for the development in intellectual human capital and the subsequent take-off of the economy. Once human capital begins to increase due to child education, the effects on technological progress and earnings determine the passage to a Modern regime of Growth. The economy finally approaches a steady state equilibrium characterized by high levels of physical and intellectual human capital, low fertility rates and large life spans.

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Appendix A: Proof of condition (14)

We are interested in finding conditions for multiple steady states of the transition function (13).[7] First, a sufficient and necessary condition for the existence of a fixed point for $z_t^P \leq \hat{z}$ is that $\hat{z} > \log(\lambda_t \varphi + \theta)$. This condition implies that the dynasty reaching the human capital level $\log(\lambda_t \varphi + \theta)$ will be endowed with the same level of human capital.

For the existence of multiple steady states, two more equilibria are needed for $z_t^P > \hat{z}$. Since the transition function is concave for $z_t^P > \hat{z}$, a condition that guarantees the existence of two more steady states is that its slope is greater than one for $z_t^P \to \hat{z}$ from above. Continuity of the transition function with respect to adult income guarantees that the slope will remain greater than one for z_t^P sufficiently close to $\hat{z}$. By supposing that λ_t and s_t are linear functions of physical status, and that this is a linear function of per capita income, the slope of the transition function for $z_t^P \to \hat{z}$ is equal to

$$\frac{\lambda_t (s_t^2 \gamma \lambda_t \varphi + s' k \beta (\vartheta + \lambda_t \varphi) + \lambda' k s_t (\beta (\vartheta + \lambda_t \varphi) - s_t \gamma \lambda_t \varphi)}{k s_t (\beta - s_t^E \gamma) \lambda_t (\vartheta + \lambda_t \varphi)}. \tag{24}$$

When this slope is greater than one, the existence of two more steady states for $z_t^P > \hat{z}$ is guaranteed. Rewriting all conditions in terms of the threshold level $\hat{z}$, leads to the formulation

[7] See Berti Ceroni (2001)

$$\log(\lambda_t \varphi + \vartheta) < \hat{z} < Z, \qquad (25)$$

where

$$Z \equiv \frac{\lambda_t (s_t^2 \gamma \lambda_t \varphi + s' k \beta (\vartheta + \lambda_t \varphi))}{s_t^2 \gamma (\beta - s_t^E \gamma) \lambda_t^2 \varphi (\vartheta + \lambda_t \varphi)} + \\ + \frac{\lambda' k s_t (\beta \vartheta + (\beta - s_t \gamma) \lambda_t \varphi)(s_t \gamma \lambda_t (1 - \varphi) + \beta (\vartheta + \lambda_t \phi))}{s_t^2 \gamma (\beta - s_t^E \gamma) \lambda_t^2 \varphi (\vartheta + \lambda_t \varphi)}. \qquad (26)$$

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