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Abstract This paper develops a two periods, overlapping generation model in order to explain the development of the foraging system and to provide a rationale for the shift to agriculture. Improved health status induced by natural selection and, subsequently, by a human-induced increase in the level of nutrition, emerges as the ultimate source of growth. As time passes, a barrier to development comes out as a consequence of the inherent incapacity of the foraging system to generate sustained technological progress. Decreasing rates of technological growth, combined with demographical pressure, may result in an involution of the foraging system.

Keywords Early Development, Hunting-gathering, Neolithic Revolution, Economic Growth

JEL classification: N10, O11, O41, J10, J13

1. Introduction

The Neolithic Revolution is probably the first and most important episode in the development of the human population. The shift from foraging to agriculture has permanently changed human life and it has been proved to be an important factor in explaining modern growth. For instance, Galor and Moav (2002) suggest that the shift from the hunter-gatherer organization to the agriculture societies amplified the evolutionary advantage of individuals with a quality-bias that resulted in economic growth; Olsson and Hibbs (2005) provide evidence on the causal relationship between biogeographic endowments in prehistory and the variation in present-day output per person. They conclude that half of the 1997 international variation in log output per person can be explained by prehistoric biogeography.

The recognized importance of the shift to farming logically implies the reflection on its origins. Since Braidwood et al. (1983), the systematic study of agriculture origins has fascinated a growing number of researches. As Weisdorf (2005) observes in his remarkable survey of the Archaeological and Economic literature on the Neolithic Revolution, many theories have been developed in order to explain this event. However, attempts made in this direction do not seem to be satisfactory (see, for instance, Smith [1995] and Fernandez-Armesto [2001]). Many authors have given climate change a key explanatory role (see, for instance, Childe [1935]). Dryer conditions after the last ice age would have determined migration to zones that were protected from desiccation and a consequent behavioural shift to farming. However, evidence suggesting that the climate change occurred at a very slow rate ruled out this possibility. During the 1960s the prevalent theory was that agriculture emerged from leisure rather than from necessity (Braidwood and Howe [1060]). But farming has been proved to be more costly and labour intensive than hunting and gathering, so that foraging may be a superior strategy at least to incipient agriculture (Harris [1977]; Cohen and Armelagos [1984]). If so, other factors may be necessary to explain the use of a less efficient production system. As reported by Weisdorf (op. cit.), Smith (1975) examined animal extinction caused by excessive hunting as the reason that favoured agriculture. North and Thomas (1977) suggest that agriculture prevailed because common property right among foragers caused incentive failure, whereas exclusive communal property rights among farmers do not. Olsson (2001) focuses on population growth and demographical pressure. Morand (2002) develops a model in which exogenous factors determine the modes of production and the implied type of intergenerational exchange.

In this paper it is argued that the process that has lead to the origin of agriculture can be understood in terms of the inherent capacity of the foraging system to generate technological progress, combined with population growth and the consequent demographical pressure.

In the very early phase of development of the human population, the ultimate source of improvement in health human capital is argued to be a natural selection process. This first stage of growth is primarily characterized by the total lack of control operated by the human beings on the level of consumption, on the ability to survive and on the capacity to generate technological progress. Moreover, population growth is “Malthusian” in that it varies depending on productivity and on unsystematic success in obtaining food. As time passes, Nature selects dynasties that are able to gather food above the subsistence level through the foraging system. This generates a progressive improvement in individual health status that is human-induced. Improved human capital, on turn, generates technological progress in terms of practices that favour a more efficient exploitation of the foraging system. However, the rate of technological progress tends to decrease in time and finally fail to compensate the growth of population. Potential income begins to decrease, and so does the health status of population; the foraging system starts to collapse. The only way to maintain or improve the per capita level of income reached with hunting and gathering, the production system has to be changed. Thus, the shift to farming emerges as a sufficient condition for the development of the human population.

These features are discussed by developing a two periods, overlapping generation model with endogenous fertility. The framework that has been used is inspired by the analysis of the Transition from the Malthusian Era to the Modern Growth regime by Galor and Weil (1999, 2000). Adults maximize a utility function that depends on family present consumption, quantity as well as quality of children. Child quality is assumed to be a function of nutrition and health status. Health status, on turn, affects both the level of human capital and the survival probability from childhood to adulthood. Survival is assumed to be selective, in that individuals in the lower cue of the distribution function of health human capital have a lower probability of surviving from childhood to adulthood. Technological progress is assumed to depend on the increase in the level of human capital and, thus, on the physical status of population.

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. In section 3 the production system and technological progress are considered. Section 4 analyses the evolution of income in the foraging system. 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. The survival probability from childhood to adulthood, s_t, is assumed to be a function of the nutritional intake above the subsistence level, a_t,

$$s_t = s(a_t), \tag{1}$$

where $0 < s_0 \equiv s(0) \leq s_t < 1,\ \partial s/\partial a > 0$ and $\partial^2 s/\partial a^2 < 0.$

In the early stages of their lives each child spends the available unit of time accumulating health human capital. The technology of production of human capital is assumed to be

$$h_{t+1} = B(\tau + a_t)^{\mu} X_t^{1-\mu}, \tag{2}$$

where $0 < \mu < 1$, human capital is measured in efficiency units of labour, τ represents the minimum amount of consumption commodity that parents dedicate to child rearing and *B* is a technological constant. X_t is assumed to be an exogenous variable that represents genetic variation, resistance to specific diseases, or other factors related to health status not considered in the model. X_t is distributed across population according to a distribution function $F_t(X)$. The heterogeneity in the level of human capital is a key factor in explaining early development. It should be noted that the only input controlled by individuals is nutrition. It is implicitly assumed, thus, the absence of any kind of educational process, being it formal or informal.

In the second period of life, adults optimally choose the level of family present consumption c_t, the number of children n_{t+1} and the amount of resources dedicated to child nutrition, a_t. Bringing up a child implies a fixed time-cost φ, related to care during infancy. It can be observed that this cost is expressed as time subtracted to work and is thus a positive function of the level of human capital of parents. Moreover, parents should dedicate a fixed minimum quantity of consumption commodity, τ, in order to nourish a child. An adult *i*, endowed with a level of human capital h_t^i, is subject to the budget constraint

$$h_t^i w_t (1 - n_{t+1}^i \varphi) - n_{t+1}^i (\tau + a_t^i) = c_t^i, \tag{3}$$

where w_t is the recompense per efficiency unit of labour. Preferences of adults born at $t - 1$ are represented by the logarithmic utility function

$$U_t^i = \alpha \cdot \log(c_t^i) + \beta \cdot \log(n_{t+1}^i) + \gamma \cdot \log(\tau + a_t^i), \tag{4}$$

where it is assumed that child quantity is preferred to child quality in terms of resources dedicated to nutrition, $\beta > \gamma$.

2.1. Utility Maximization

Adults choose c_t^i, n_{t+1}^i and a_t^i in order to maximize (4) subject to (3). Results implied by the first order conditions of the maximization problem depend on the initial level of adult potential income. In particular, when

$$h_t^i w_t \equiv z_t^i \geq \frac{(\beta-\gamma)\tau}{\gamma\varphi} \equiv \hat{z} \tag{5}$$

holds, an interior solution exists and the optimal levels of the choice variables are

$$n_{t+1}^i = \frac{\beta-\gamma}{(\alpha+\beta)\varphi} \equiv n_{MAX} \ , \tag{6a}$$

$$a_t^i = \frac{(z_t^i\varphi+\tau)\gamma-\beta\tau}{\beta-\gamma}. \tag{6b}$$

It should be noted that the fertility rate is constant and, in addition, it is at its maximum level. The amount of consumption commodity dedicated to child nutrition increases with adult income. The solution characterized by (6a) and (6b) results in an implicit value of the survival probability, as follows from (1). In particular, since $\partial a_t / \partial z_t > 0,$ it should be noted that $\partial s_t / \partial z_t > 0.$ When it is assumed that

$$z_t^i \leq \hat{z}, \tag{7}$$

first order conditions of the maximization problem imply

$$n_{t+1}^i = \frac{z_t^i\beta}{(\alpha+\beta)(z_t^i\varphi+\tau)}, \tag{8a}$$

$$a_t^i = 0. \tag{8b}$$

The fertility rate increases with adult income, parents do not allocate resources to child nutrition above the subsistence level τ, and the probability of surviving from childhood to adulthood is constant and equal to

$$s_t = s_0 > 0. \tag{9}$$

On considering the initial situation of the human being in the foraging system, it would be rational to suppose that every individual within this economy is endowed with a very low level of human capital. Hence, (8a) and (8b) characterize the solution of the maximization problem that has to be taken into account. In order to analyse the temporal evolution of this model economy, the system of production has to be considered.

3. Production and Technological Progress

Food production occurs to a constant-returns-to-scale technology subject to endogenous technological progress. The output at t is produced according to

$$Y_t = H_t^{\eta}(A_t R)^{1-\eta}, \tag{10}$$

where $0 < \eta < 1$, H_t and R are the quantities of efficiency units of labour and resources employed at t and $A_t > 0$ represents the technological level at t. Where $h_t = H_t/L_t$ and $r_t = (A_t R)/L_t$ are the efficiency units of labour per adult and the amount of "effective resources" per adult respectively, the output per unit of adult at t is

$$y_t = h_t^{\eta} r_t^{1-\eta}. \tag{11}$$

If it is assumed that there are no property rights with respect to resources, as it is expected that occurred in the foraging system,[1] the recompense per efficiency unit of labour is equal to its average product,

$$w_t = \left(\frac{r_t}{h_t}\right)^{1-\eta} . \tag{12}$$

Since adults are heterogeneous in the level of human capital, it is expected that individuals endowed with a better health status receive a higher recompense. However, by considering the hypothesis of communal organization of the foraging societies, it is assumed that production is equally distributed across all adults.[2] Consequently, each adult receives, directly or by redistribution, the same amount of outcome.

The rate of technological progress depends on the increase in the average level of human capital in the population,

$$g_t = g(\frac{\partial h_t}{\partial t}) , \tag{13}$$

where $\partial g \big/ \partial(\partial h_t / \partial t) > 0$, $\partial^2 g \big/ \partial(\partial h_t / \partial t)^2 < 0$ and $g(0) = 0 \leq g_t < 1.$

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. In the first phase of development, this is primarily reached through improved health status. As it will be shown in somewhat more detail, this assumption is key in generating the fall of the foraging system. Explicitly, since human capital increases with income at decreasing rates, technological progress will gradually fall and, eventually, the level of technology may turn out to be constant in absence of improving human capital.

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

$$z_{t+1} = z_t \left[\frac{(1+g_t)}{s_t n_{t+1}} \right]^{1-\eta} \cdot \left[\frac{h_{t+1}}{h_t} \right]^{\eta}, \tag{14}$$

that follows from (12) and the hypothesis of communal organization. When adult income is below the level that allows for improved child nutrition, (14) reduces to

$$z_{t+1} = z_t \left[\frac{(1+g_t)}{s_0 \dfrac{z_t \beta}{(\alpha+\beta)(z_t \varphi + \tau)}} \right]^{1-\eta} \left(\frac{\overline{X}_{t+1}}{\overline{X}_t} \right)^{\eta(1-\mu)}, \tag{15}$$

where $\overline{X}_t = \int X_t dF_t(X)$. It is initially assumed that $\overline{X}_t = \overline{X}_{t+1} \Rightarrow \partial h_t / \partial t = 0 \Rightarrow g_t = 0$. The transition function (15) provides the stable fixed point

$$z^* = \frac{(\alpha+\beta)\tau}{s_0 \beta - (\alpha+\beta)\phi}. \tag{16}$$

Hence, the foraging system appears to be locked into a poverty trap at its genesis. Logically therefore two questions pose themselves; first, how does an economy of foragers grows? And second, is it possible, from a theoretical point of view, to explain the fall of the foraging system and to provide a rationale for the adoption of agriculture?

4. Evolution of the Foraging System

Improved health status is a key factor in determining growth. The causal relationship between health and economic development has been demonstrated by a growing number of theoretical and empirical analyses, since Fogel (1994a, 1994b, 2002) and Fogel and Wimmer (1992). Arora (2001), investigating the growth path of 10 industrialized countries over 100 to 120 years, provides historical evidence of the importance of health for economic growth. According to this analysis, health increased the pace of growth of these countries by 30 to 40 percent, altering permanently the slope of the growth path. Other papers confirm this conclusion such as Doppelhofer, Sala-i-Martin and Miller (2004), Mayer-Foulkes et al. (2001), Bhargava (2001) and Schultz (1999), among others.

Health status, on turn, is primarily affected by the quantity and quality of nutrition.[3] For instance, English et al. (1997) establishes that deficiency of protein energy and a number of micronutrients compromise the immune system and, in many cases, the integrity of epithelial tissues, which lowers defences to pathogenic invasion. It should be noted, however, that poor body builds increase vulnerability to both contagious and chronic diseases. Fogel (2004) illustrates that chronic conditions were much more frequent among short young men that among tall men in the National Health Interview Surveys for 1985-88. Moreover, stunting during development ages increases the likelihood that people would suffer from chronic diseases at middle and late ages. As reported by Galor and Mayer (2004), there is an entire body of literature that shows that malnutrition leads to decreases in longevity, chronic diseases and lower cognitive status. Extrapolating these results to an economic system of foragers, it can be reasonably assumed that improved health status has been the ultimate source of growth.

The model presented in this paper predicts that the amount of consumption commodity initially dedicated to child nutrition and, thus, health status, is stuck at the subsistence level, as follows from (8b). In absence of a formal or informal educational system, that could improve intellectual human capital, the only resource is the human machine. Nonequilibrium thus emerges as the only opportunity of growth in the first phase of development. When there is no technological progress, if

$$z^* > \hat{z},, \tag{17}$$

the transition function does not provide any steady state for $z_t \in [0; \hat{z}]$. It should be noted, however, that this condition holds if and only if population growth is below the replacement level. In fact,

$$z^* > \hat{z} \Leftrightarrow s_0 < \frac{\alpha + \beta}{(\beta - \gamma)}\varphi \tag{18}$$

and

$$s_0 < \frac{\alpha + \beta}{(\beta - \gamma)}\varphi \Rightarrow s_0 n_{t+1} < 1. \tag{18a}$$

Explicitly, potential income increases only when the survival probability is sufficiently low to compensate the effects of augmenting fertility rates on population growth. It is consequently evident that further assumptions are needed in order to modelling growth in the foraging system.

4.1. Natural selection

It has been assumed that individuals are heterogeneous in the levels of human capital. In particular, the variable X_t of health-related exogenous factor is assumed to be distributed across population according to a given distribution function $F_t(X)$. In order to explain growth in this apparently stable system of foraging, it is supposed that the survival probability, s_t, is selective. In other words, individuals in the lower cue of the distribution function of health human capital have a lower probability of surviving from childhood to adulthood. This slow and continuous natural selection process results in the progressive survival of individuals with greater resistance to natural adverse conditions, improved capacity to assimilate food and transform it into energy, or better physical condition in a broad sense. The main consequence of this process of selection is the slow, incessant increase in the level of human capital. Therefore, supposing that the work of Nature is continuous and roughly constant, the last term at the right side of the transition function (15) is greater than one. Moreover, improving human capital causes technological progress by (13). Consequently, the nonequilibrium condition has to be rewritten as

$$s_0 < \frac{(1+\tilde{g})(\alpha+\beta)(\overline{X}_{t+1}/\overline{X}_t)^{(1-\mu)/(1-\eta)}(\beta-\gamma(1-\tau))}{\beta(\beta-\gamma)}\varphi\,, \tag{19}$$

where $\tilde{g}$ is the rate of technological progress induced by the improvement in the level of human capital. Since the natural selection process is assumed to be constant, the growth of human capital and, thus, technological progress are constant.

The increase in the levels of human capital operated by natural selection allows for the possible existence of population growth in this instable economic system of hunter-gatherers.

Proposition **P1**: The very early stage of development is characterized by “Malthusian” population growth, a constant and low probability of survival from childhood to adulthood, and consumption at subsistence levels. The ultimate source of development is the nonequilibrium of a system in which population growth can be positive thanks to the process of natural selection.

Therefore, the main characteristic of this first phase of development of the foraging system is the absolute lack of control operated by individuals on the level of consumption, on the ability to survive and on the capacity to generate growth. Fertility may increase or decrease depending on the exogenous availability of resources or on the unintentional success in obtaining food. Survival is a matter of chance. The evolution of the human being is due to the imperceptible but continuous work of Nature.

It should be noted that this situation is expected to prevail in the very long term, until when potential income exceeds the threshold level $\hat{z}$. From this point on, the amount of resources dedicated to child nutrition allows for a development of health human capital that is human-induced, as follows from (2) and (6b).

4.2. Human-induced improvement in physical status

It is now assumed that the dynasties that have survived to the selection process have the physical capacity to generate an output greater than the threshold $\hat{z}$. As follows from the results of the maximization problem, adults chose to allocate to child consumption an amount of resources greater than the subsistence level. Population growth turns out to be "Boserupian" in this situation.[4] The transition function of potential income is obtained by (2) and substituting (7a) and (7b) in (14). In order to simplify the analysis, it is assumed that the effect of natural selection is gradually less important for growth, and it is not taken into account. The rationale behind this assumption is that population is expected to have an increasing probability of surviving from childhood to adulthood and, thus, a decreasing proportion of individuals suffer the selection process. Hence,

$$z_{t+1} = z_t \left\{ (1+g_t)/\left[s_t \frac{\beta-\gamma}{(\alpha+\beta)\varphi} \right] \right\}^{\frac{1-\eta}{1-\mu\eta}}. \tag{20}$$

When potential income is above the threshold level $\hat{z}$, the increase in human capital [given by (2) and (7a)] results in two distinct effects. First, it generates an increase in the growth rate of technology as follows from (13); second, the survival probability s_t increases, see (1). The variation of technological progress relative to population growth determinates the evolution of potential income. If

$$(1+g_t) > \left[s_t \frac{\beta-\gamma}{(\alpha+\beta)\varphi} \right] \tag{21}$$

holds, then potential income increases from one period to the next. For this condition to hold, starting from the pseudo-equilibrium of the first stage of development of the foraging system, it is necessary that the increase in technological progress that results from improved human capital is greater than the increase in population growth,

$$\frac{\partial g_t}{\partial(\partial h_t/\partial t)} > \frac{\beta-\gamma}{(\alpha+\beta)\varphi}\frac{\partial s_t}{\partial h_t}. \tag{22}$$

It is argued that, initially, the increase in the growth rate of human capital causes a slow rise of its level. In other words, improved human capital generates technological progress in terms of the discovering of instruments and practices that made possible a more and more efficient exploitation of the prevalent production system. Improved technology will then gradually results in larger life expectancies.

Proposition **P2**: The late stage of the foraging system is characterized by "Boserupian" population growth; improving health human capital and technology makes available for consumption a growing amount of resources. Health status begins to increase thanks to the contribution of individuals, and natural selection becomes less and less important.

A population growth that is independent from productivity or income is usually held to have characterized a sedentary organization. The sedentary lifestyle, on turn, is generally supposed to be an attribute of individuals involved in farming. For instance, the fact that land was not constrained at the time has lead to the belief that agriculture resulted in increased size of families, regardless of productivity (see Olson [2001]). The model predicts, however, that "Boserupian" population growth and related sedentary lifestyle are not a consequence of the introduction of agriculture. This conclusion is consistent with the evidence that suggests a shift to sedentary lifestyle prior to and independent of the transition to agriculture (Bar-Yosef and Belfer-Cohen [1989, 2000]).

4.3. Decreasing technological progress and the fall of the foraging system

The increase in nutrition generates a progressive improvement in the level of human capital. However, this improvement occurs at diminishing rates. Since the growth rate of technology depends on the variation in the level of human capital by (13), the rate of technological progress tends to decrease in the long run. On the contrary, when the level of human capital increases, although at diminishing rates, the survival probability continues to increase. In other words, as time passes, the left side of (22) tends to diminish, while the right side of the same inequality, that is population growth, tends to increase. As a consequence, the economy will approach a point at which income levels begin to decrease. It should be noted that when potential income approaches a level such that

$$(1+g_t)=\left[s_t\,\frac{\beta-\gamma}{(\alpha+\beta)\varphi}\right] \tag{23}$$

holds, the level of potential income is the same at *t* and at *t* + 1. However, this situation does not characterize an equilibrium. Since $z_t = z_{t+1} \Rightarrow \partial h_t / \partial t = 0 \Rightarrow g_t = 0,$ potential income and the survival probability will fall to approach the population replacement level equilibrium

$$s^*(\tilde{z})\,\frac{\beta-\gamma}{(\alpha+\beta)\varphi}=1. \tag{23}$$

Proposition **P3**: After a period of growth, the foraging system tends to collapse. Constant fertility and increasing life spans result in demographical pressure. This variable, combined to the impossibility of sustained technological growth, causes the progressive decrease of potential income.

Therefore, the model predicts that the main cause for the fall of this economic system is not the decreasing productivity of foraging caused, for instance, by animal extinction (Smith [1975]), nor the incentive failure caused by common property rights among foragers (North and Thomas [1977]), nor is it due to exogenous factors. The fall of the foraging system was due to its inherent impossibility of generating sufficient technological progress to compensate the growth of population. The main conclusion is that for an economic system to go on growing, at least one of these two conditions needs to be satisfied. The first is related to demographical pressure. If population growth is controlled, per capita income could grow even if productivity decreases. The reduction of demographical pressure, however, implies the existence of a complex organization, with the instruments and the capacity to limit the individual choice about the family size. It is argued that this is not the relevant scenario prior to the Neolithic Revolution. The second possibility is the shift to a new system of production, characterized by higher technological potential.

5. Conclusions

In this paper a two period, overlapping generation model is developed in order to explain the growth of the foraging system and to provide a rationale for the shift from hunting and gathering to agriculture.

From the model emerges that the history of the human population prior to the Neolithic revolution can be divided in three distinct phases. The first period of early development is characterized by the total dependence on Nature of the human being. Consumption never exceeds the subsistence level, survival to adverse external conditions is a matter of chance, and individuals do not have the possibility or capacity to increase the production of food. Moreover, population growth is “Malthusian” in that in depends on the availability of resources and on unsystematic gathering. However, a continuous and time-consuming natural selection process determinates the survival of those dynasties, which are endowed with improved health status. Nonequilibrium of the system allows for the progressive increase in potential income towards a level at which adults dedicate resources to child nutrition above the subsistence level. This results in a development of health status that is human-induced, and provides the human being with an instrument to control the evolution of the specie. In this second period of development of the foraging system, population growth turns out to be “Boserupian”. Since a population growth that is independent from productivity and the quantity of output appears to be related to a sedentary lifestyle, the prediction of the model is consistent with the empirical evidence that suggests a shift to the sedentary lifestyle prior to and independent of the introduction of agriculture (Bar-Yosef and Belfer-Cohen [1989, 2000]). Technological progress progressively increases with health human capital, although at decreasing rates. On the contrary, the combination of “Boserupian” population growth and increasing life spans (due to improved health status) results in demographical pressure. The third and last period of the foraging society is characterized by the incapacity of generating sustained technological progress in order to compensate the growth of population. This generates an involution of the system.

Two solutions emerge with the aim of maintaining or increasing the maximum level of per capita income achieved with the hunting-gathering system. The first is concerned with the decrease of fertility rates that would allow for increasing per capita income; however, this would require more complex organizations, with the capacity to constraint the individual choice. The second solution is the revolutionary shift to a production system with greater potential.

Notes

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[1] See North and Thomas (1977).

[2] See, for instance, Gabeuer and Price (1992) or Fernandez-Armesto (2000).

[3] The influence of medical factors before the twentieth century have played a modest role in the reduction in mortality, and thus in the Transition of most western countries (see, for instance, Omran [1971])

[4] See Boserup (1965).

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