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Evolution and growth☆

Oded Galor[a,b,c,*], Omer Moav[b,c]

[a]Department of Economics, Brown University, Providence, RI 02912, USA
[b]Department of Economics, Hebrew University, Jerusalem 91905, Israel
[c]CEPR, London, UK

Abstract

This paper presents an evolutionary growth theory that captures the interplay between the evolution of mankind and economic growth since the emergence of the human species. This unified theory encompasses the observed evolution of population, technology and income per capita in the long transition from an epoch of Malthusian stagnation to sustained economic growth. © 2001 Elsevier Science B.V. All rights reserved.

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1. Introduction

This paper presents an evolutionary growth theory that captures the interplay between the evolution of mankind and economic growth since the emergence of the human species. The theory encompasses the observed intricate evolution

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* Corresponding author. Department of Economics, Brown University, Providence RI 02912, USA. Tel.: + 1-401-863-2117; fax: + 1-401-863-1970.
E-mail address: oded_galor@brown.edu (O. Galor).

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of population, technology and output in the long transition from an epoch of Malthusian stagnation to sustained economic growth. The proposed theory presents a revolutionary hypothesis about the origin of sustained economic growth. According to this hypothesis, prolonged economic stagnation prior to the transition to sustained growth stimulated natural selection that shaped the evolution of the human species, whereas the evolution of the human species triggered the take-off from an epoch of Malthusian stagnation to sustained economic growth.

2. Historical background

For the major part of human existence economies appear to be in a Malthusian stagnation. Diminishing returns to labor along with a positive effect of the standard of living on the growth rate of population provided a self-equilibrating role for the size of the population in a stationary economic environment. Changes in the technological environment or in the availability of land lead to larger but not richer population. The growth rate of output per capita had been negligible over time and the standard of living had not differed greatly across countries. For instance, the average growth rate of GDP per capita in Europe between 500 and 1500 was nearly zero (Maddison, 1982). Similarly, the pattern of population growth over this era follows the Malthusian pattern. The average annual rate of population growth in Europe between 500 and 1500 was 0.1 percent, and world population grew at an average pace of less than 0.1 percent per year from the year 1 to 1750, reflecting the slow pace of resource expansion and technological progress. Fluctuations in population and wages also bear out the structure of the Malthusian regime. For instance, negative shocks to population, such as the Black Death, were reflected in higher real wages and faster population growth.[1]

The emergence from Malthusian stagnation was initially very slow. The average growth rate of income per capita in Europe was only 0.1 percent per year between 1500 and 1700, and 0.2 percent between 1700 and 1820. As income per capita grew, population growth increased as well. During this slow transition, the Malthusian mechanism linking higher income to higher population growth continued to function, but the effect of higher population on diluting resources per capita, and thus lowering income per capita, was counteracted by technological progress, which allowed income to keep rising. The take-off from Malthusian stagnation intensified in Europe during the Industrial Revolution and the average growth of output per capita over the period 1820–1870 rose to an annual rate of 1.0 percent.

[1] For a comprehensive description of the stylized facts regarding the evolution of population, education and output see Galor and Weil (2000).

Fertility rates increased in most of Western Europe until the second half of the nineteenth century and the level of resources invested in each child increased as well.[2] Ultimately, a demographic transition was triggered. Population growth fell and brought about sustained increase in income per capita of 2.2 percent over the period 1929–1990.

3. Historical puzzles and existing theories

The historical evidence suggests that the key events that separate the epoch of Malthusian stagnation and the Sustained Growth Regime are the acceleration in the pace of technological progress and the demographic transition. The emergence from the Malthusian trap and the onset of the demographic transition raise intriguing questions. Why has the link between income per capita and population growth so dramatically reversed? How does one account for the sudden spurt in growth rates? Why had waves of rapid technological progress not generated sustained economic growth in the Pre-Industrial Revolution era? And is there a unified framework of analysis that can account for this intricate evolution of economic growth and mankind since the origin of the human species?

The inconsistency of exogenous as well as endogenous neoclassical growth models with the evolution of economies throughout most of human history has lead recently to the development of unified growth models that are consistent with an epoch of Malthusian stagnation and the transition from Malthusian stagnation to sustained growth. In light of the central role that the interaction between population growth and technological change has apparently played in the Malthusian world as well as in the take-off to sustained growth, these unified models are based on endogenous population growth and endogenous technological change.[3] In addition they incorporate the main Malthusian features. Galor

[2] During the 19th century the average years of education nearly quadrupled in England.

[3] The existing literature on the relation between population growth and output has tended to focus on only one of the regimes described above. The majority of the literature has been oriented toward the modern regime, trying to explain the negative relation between income and population growth either cross-sectionally or within a single country over time. Among the mechanisms highlighted in this literature are: (a) higher returns to child quality in developed economies induce a substitution of quality for quantity (Becker et al., 1990); (b) developed economies pay higher relative wages for women, thus raising the opportunity cost of children (Galor and Weil, 1996); (c) the net flow of transfers from parents to children grows as countries develop (Caldwell, 1976; Morand, 1999); (d) higher fertility rates among unskilled workers increases the return to skills and an incentive to substitute quality for quantity (Dahan and Tsiddon, 1998). Recent Malthusian models include the work of Kremer (1993) and Lucas (1999). Kremer (1993) models a reduced form interaction between population and technology along a Malthusian equilibrium, and Lucas presents a Malthusian model in which households optimize over fertility and consumption.

and Weil (1999, 2000) argue that the inherent positive interaction between population and technology during the Malthusian regime had gradually increased the rate of technological progress, inducing investment in human capital that lead to further technological progress, a demographic transition, and sustained growth.[4]

4. Evolutionary theories

This paper presents unified evolutionary theories that focus on the interaction between the evolution of the human species and the transition from a Malthusian Epoch to sustained growth. The paper focuses on three different evolutionary mechanisms: The evolution of intelligence, health, and preference for child quality.

The fundamental premise that has guided this research is that, due to natural selection, the composition of characteristics of the population, that may be highly relevant for the understanding of the origin of economic growth, has not been stationary since the emergence of the human species. The theories focus mostly on the change in the composition of types within Homo Sapiens (i.e., variants within the species) rather than the more dramatic evolution from Homo Erectus to Homo Sapiens, for instance. Namely, the theories focus on the evolution of the composition of types within a population that has only a modest variety in genetic traits across types.[5] Evidence regarding natural selection in nature suggests that an evolutionary process in the composition of types is rather rapid.[6]

4.1. *The evolution of preference for child quality*

Galor and Moav (2000b) develop a unified evolutionary theory that encompasses the observed intricate evolution of population, technology and

[4] Hansen and Prescott (2000) develop a model in which an exogenous technological progress in a latent industrial technology along with an assumed hump-shaped evolution of population growth in the process of development brings about a transition from a stagnating agricultural economy to a growing industrial economy. Jones (2000) suggests that the virtuous circle between the size of the population and the production of ideas along with the improvement in institutions that promote innovation have lead to the transition from stagnation to growth. Recent growth models with endogenous fertility of the long transition from stagnation to growth also include Galor and Mountford (2000), Morand (2000), Kogel and Prskawetz (2001), Lagerloff (2000), Tamura (2000), among others. For endogenous transition that is not based on endogenous fertility see: Arifovic et al. (1997), Sorensen (1999) and Kelly (2001).

[5] The evolution from Homo Erectus to Homo Sapiens, in contrast, in which brain size nearly doubled, had taken more than 1 million years.

[6] See for instance the field experiments on industrial melanism in Kettlewell (1973).

output in the long transition from a Malthusian epoch to sustained economic growth. Consistently with existing evidence, the theory suggests that during the Malthusian era technology evolved rather slowly and population growth prevented a sustained rise in income per capita. Human beings, like other species, have confronted the basic trade-off between offspring's quality and quantity in their implicit Darwinian survival strategies.[7] Although quantity-biased preferences had a positive direct effect on fertility rates, it adversely affected the quality of offspring, their fitness, and hence their fertility rates. The inherent evolutionary pressure in the Malthusian era generated an evolutionary advantage to quality-biased preferences. Natural selection therefore increased the quality of the population inducing faster technological progress that brought about the take-off from the era of stagnation and thereafter a demographic transition that paved the way to sustained economic growth.

The theory is based on four fundamental elements. The first element of the model consists of the main ingredients of a Malthusian world. The economy is characterized by a fixed factor of production, land, and a subsistence consumption constraint below which individuals cannot survive. If technological progress permits output per worker to exceed the subsistence level of consumption, population rises, the land–labor ratio falls, and in the absence of further technological progress, wages fall back to the subsistence level. Income per capita is therefore self-equilibrating and the economy is in a Malthusian stagnation. Sustained technological progress, however, can overcome the offsetting effect of population growth, by increasing effective resources per capita (i.e. the combined input of technology and land per capita), allowing sustained income growth.

In the Malthusian era, therefore, human beings struggled for survival and their fertility rates had been positively influenced by their excess income over the subsistence level of consumption. Differences in income generated therefore, differences in fertility rates across individuals. Moreover, if differences in income across individuals reflected differences in genetic traits (e.g., preferences, and physical or intellectual ability), then the effect of the Malthusian pressure on fertility rates would affect the genetic composition of the population.

The second element of the theory incorporates the main ingredients of the Darwinian world (i.e., variety, natural selection, and evolution) in a Malthusian economic environment. It demonstrates the importance of the Malthusian pressure for the evolution of the human species. The economy is populated with individuals whose genetic traits reflect the implicit Darwinian survival strategy. Although individuals do not operate consciously so as to assure the evolutionary advantage of their type (i.e., their variant within the species), the existence of

[7] In other species this trade-off is implicit in their biological mechanism.

variety of types enables nature to select those who fit the economic environment, increasing the likelihood of the survival of the human species in a changing world.

Inspired by fundamental components of the Darwinian theory, individuals' preferences are defined over consumption above a subsistence level as well as over the quality and the quantity of their children. These simple and commonly used preferences may be viewed as the manifestation of the Darwinian survival strategy and represents the most fundamental trade-off that exists in nature. Namely, the trade-off between resources allocated to the parent and the offspring, and the trade-off between the number of offspring and the resources allocated to each offspring.

Resources allocated to parental consumption beyond the subsistence level raise the parental labor productivity and resistance to adverse shocks (e.g., famine, disease, and variability in output), generating a positive effect on the fitness of the parent and the survival of the lineage. This positive effect, however, is counterbalanced by the implied reduction in the resources allocated to the offspring, generating a negative affect on the survival of the lineage.

The significance that the individual attributes to child quantity as well as child quality reflects the well known variety in the quality–quantity survival strategies that exists in nature. Although a quantity-biased preference has a positive effect on fertility rates and may therefore generate an evolutionary advantage, it adversely affects the quality of offspring, their fitness, and their income. Hence, in the pre-demographic transition era, when fertility rates are positively associated with income levels, a quantity-biased preference may generate an evolutionary disadvantage.

The economy consists of a variety of types of individuals distinguished by their genetic traits (i.e., preference for child quality) that affect their income and fertility. The household chooses the number of children and their quality (i.e., resources invested in each child) in the face of a constraint on the total amount of resources that can be devoted to child raising and labor market activities. Traits are hereditary and hence the distribution of types (i.e., the distribution of individuals who differ with respect to these traits) evolves over time due to the effect of natural selection. The economic environment determines the type with the evolutionary advantage (i.e., the type characterized by higher net fertility rates) which may alter over time due to changes in the environment.

The third element of the model links the evolution of the human species to the process of economic growth. Following the well-documented and commonly employed hypothesis, human capital is assumed to have a positive effect on technological progress and therefore on economic growth.[8] Hence, if natural selection, as determined by the Malthusian pressure, brings about an increase in

[8] This link between education and technological change was proposed by Nelson and Phelps (1966). For supportive evidence see Easterlin (1981) and Doms et al. (1997).

the representation of individuals who invest more in child quality, then the implied evolution in the composition of types generates an increase in the rate of technological progress.

The fourth element links the rise in the rate of technological progress to the demographic transition and sustained economic growth. A rise in the rate of technological progress is assumed to increase the rate of return to human capital, inducing parents to substitute child quality for child quantity.[9] The argument that technological progress itself raises the return to human capital was most clearly stated by Nelson and Phelps (1966) and Schultz (1964).[10]

Technological progress has therefore two effects on the evolution of population. First, it increases the return to human capital, inducing parents to raise the quality of each child and reduce the number of children. But, second, by raising parental income above the subsistence level, technological progress provides more resources for quality as well as quantity of children. Hence, an increase in the rate of technological progress increases the average quality in the population, further accelerating technological progress. Ultimately, technological progress becomes sufficiently rapid so as to induce a reduction in fertility rates, generating a demographic transition and sustained economic growth.

The interaction between these four fundamental elements generates an evolutionary pattern that is consistent with the observed evolution of the world economy and the human population from Malthusian stagnation to sustained growth.

Suppose that in the early era in the history of mankind, the population of the world consisted of homogeneous individuals of the "quantity type" who place low weight on the quality of their offspring. Given the initial conditions, the economy is in a locally stable Malthusian steady-state equilibrium where technology is stationary, parents have no incentive to raise quality children, and hence the level of human capital, effective resources, output per capita, and population are constant as well. Deviations from this steady-state equilibrium, due to some exogenous shocks to population or resources are undone in a classic Malthusian fashion.

Mutation introduces a very small number of individuals of the "quality type" – who place higher weight on the quality of their children.[11] Subsequently, in

[9] Unlike Becker (1981) in which a high level of income is inducing parents to switch to having fewer, higher quality children, the substitution of quality for quantity in this paper is in response to technological progress.

[10] Schultz (1975) cites a wide range of evidence in support of this theory. Similarly, Foster and Rosenzweig (1996) find that technological change during the green revolution in India raised the return to schooling, and that school enrollment rates responded positively to this higher return.

[11] One should not be concerned about the possibility that this mutation would have an evolutionary advantage much earlier in history. This is a simplifying assumption that is designed to capture a sequence of mutations, which result in a gradual increase in the variance in the distribution of the quality parameter.

every period the economy consists of two types of individuals: Individuals of the "quality type" – with a higher weight for quality, and individuals of the "quantity type" – with a lower weight for quality. In the initial periods after the mutation affects the economy the fraction of individuals of the quality type is small, the rate of technological progress is slow, inducing little investment in quality, and resulting in proportional increases in output and population. The economy remains therefore in the vicinity of a temporary locally stable Malthusian steady-state equilibrium.

In the early Malthusian era, when humans merely struggle for survival, individuals with a preference bias towards quality of offspring have an evolutionary advantage over individuals of the quantity type. That is, the fraction of individuals of the quality type rises in the population, despite their preference bias against the quantity of their offspring. Hence, in early stages of development the Malthusian pressure provides an evolutionary advantage to the quality type. The income of individuals of the quantity type is near subsistence and fertility rates are therefore near replacement level. In contrast, the wealthier, quality type, can afford higher fertility rates (of higher quality offspring). The fraction of individuals of the quality type in the population increases monotonically over this Malthusian regime, generating higher rates of technological progress.

As the fraction of individuals of the quality type increases, technological progress intensifies, and ultimately the dynamical system changes qualitatively, the Malthusian temporary steady-state vanishes endogenously and the economy takes-off from the Malthusian trap. The positive feedback between the rate of technological progress and the level of education reinforces the growth process, setting the stage for the Industrial Revolution. The increase in the rate of technological progress brings about two effects on the evolution of population and its quality. On the one hand, improved technology eases households' budget constraints, providing more resources for quality as well as quantity of children. On the other hand, it induces a reallocation of these increased resources toward child quality. Hence, an increase in the rate of technological progress increases the average quality in the population, further accelerating technological progress. In the early stages of the transition from the Malthusian regime the effect of technological progress on the parental budget constraint dominates, and the population growth rate as well as the average quality increases. Ultimately, however, technological progress becomes sufficiently rapid so as to induce a reduction in fertility rates, generating a demographic transition in which the rate of population growth declines along with an increase in the average level of education. The economy converges to a steady-state equilibrium with sustained growth of output per worker.

During the transition from the Malthusian stagnation to the sustained growth regime, once the economic environment improves sufficiently the evolutionary pressure weakens, the significance of quality for survival (fertility) declines, and individuals of the quantity type gain the evolutionary advantage. Namely, as technological progress brings about an increase in income, the Malthusian pressure relaxes, and the domination of wealth in fertility decisions diminishes. The inherent advantage of the quantity type in reproduction gradually dominates and fertility rates of the quantity type ultimately overtake those of the quality type. The fraction of individuals of the quality type starts declining and the long run equilibrium is dominated by the quantity type. Nevertheless, the growth rate of output per worker may remain high.

Unlike previous unified theories, the presence of heterogeneity in the proposed theory generates predictions regarding the evolution of fertility across individuals within a time period, as well as over time. The theory predicts that fertility differential across income groups evolves non-monotonically in the process of development. In any period within the Malthusian Regime fertility rates among richer individuals are predicted to be higher than those among poorer individuals, whereas in any period within the Modern Growth Regime fertility rates among richer individuals are predicted to be lower than those among poorer individuals. (e.g., Lee, 1987; Boyer, 1989; Livi-Bacci, 1997).

The theory suggests that the interaction between the composition of the population and the rate of technological progress determines the timing of the transition from stagnation to growth. In particular, the theory indicates that waves of rapid technological progress in the Pre-Industrial Revolution era (e.g., during the Greco-Roman period) had not generated sustained economic growth due to the distribution of genetic traits that prevented a sufficient shift to quality in response to the higher rate of technological progress. Although the return to quality increased temporarily, the level of human capital that was generated by the response of the existing population was not sufficient to support sustained technological progress and economic growth.

4.2. *The evolution of intelligence*

An alternative mechanism that would generate a similar hypothesis would be based on the evolution of intelligence. Suppose that individuals are identical in preferences for consumption above a subsistent level and for child quality and quantity, but differ in hereditary innate ability (intelligence) and hence in income and in investment in child quality. Suppose that the offspring's level of human capital is an increasing function of two complementary factors: Innate ability and parental investment in quality, where the degree of complementarity rises in a changing technological environment.[12] Thus, since the marginal return to investment in child quality increases with ability, higher ability individuals

[12] See Goldin and Katz (1998) and Galor and Moav (2000a).

and hence dynasties would allocate a higher fraction of their resources to child quality.

In the early Malthusian era individuals with higher ability generated more income and hence were able to allocate more resources for child quality and quantity. High ability individuals, however, responded to their children's high ability, by shifting resources from quantity to quality generating a negative effect on fertility rates. Since technological change in this era was slow, the income effect dominated, fertility rates of high ability individuals were higher and they enjoyed an evolutionary advantage over individuals of lower ability. As the fraction of individuals of the high ability type had increased, investment in quality has increased, and technological progress intensified. As discussed in Section 4.1, once the evolutionary process triggers the positive feedback between the rate of technological progress and the level of education, economic growth is reinforced, setting the stage for the demographic transition and a take-off to sustained economic growth.

4.3. The evolution of health

Additional evolutionary processes may explain the transition from an epoch of Malthusian stagnation to sustained economic growth. Any hereditary human trait, physical or mental, that has an impact on the quality choice of individuals may increase, via natural selection, the aggregate investment in human capital and hence may trigger the positive feedback loop between quality and technological progress that (as discussed in Section 4.1) leads to the take-off from stagnation to growth, via a demographic transition.

Suppose that individuals differ in their level of health, due to hereditary factors. Suppose further that there exist a positive interaction between the level of health and economic well being. While higher income generates a higher health level, a higher health level increases labor productivity and life expectancy and hence raises the return to human capital inducing parents to reallocate resources toward child quality. In the Malthusian era fertility rates are dominated by the income effect generated by higher parental health bringing about an evolutionary advantage to genetically healthier individuals. Natural selection therefore, increases the level of health as well as the quality of the population. Eventually, this process triggers a positive feedback loop between investment in child quality, technological progress and health, bringing about a transition to sustained economic growth with low fertility rates and high longevity.

5. Concluding remark

We wish to conclude by stressing our viewpoint that a profound understanding of the process of development and the origin of sustained economic growth necessitates an exploration of the interplay between, natural selection, the evolution of the human species and the process of development.

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