Economic Growth: Technical Progress, Population Dynamics and Sustainability

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Abstract

Economic growth is probably the most important goal of every policy intervention because of its wide consequences on the welfare of current and future generations. Because of the current crisis faced by several industrialized countries, this is probably much clearer today than in the past. In order to determine whether and which kind of public intervention can be taken to restore the growth process, the first step is understanding the relationship between different factors and economic growth. The goal of this brief paper is to shed some light on the mutual implications of growth and some of these factors: demography, technology and environment.

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1 Introduction

Economists have always known that growth is important. To understand the importance of economic growth, consider the long-run development of the U.S. economy: the real per capita GDP grew by a factor of 10 between 1870 and 2000 and this increase corresponds to an average growth rate of (only) 1.8% per year. Even a low (strictly positive) growth rate, with probably insignificant implications in the short-run, can lead to huge welfare improvements in the long-run: this is the powerful of economic growth. Therefore, the core of the discipline is understanding which factors are the main sources of such growth process and which policies can foster long-term performance of different economies. The main goal of the economic growth literature is probably answering the question raised firstly by Lucas (1988) more than 20 years ago: *"Is there some action a government of India could take that would lead the Indian economy to grow like Indonesia's or Egypt's? If so, what, exactly? If not, what is it about the 'nature of India' that makes it so? The consequences for human welfare involved in questions like these are simply staggering: Once one starts to think about them, it is hard to think about anything else"*. A clear answer to such questions does not exist yet, but a common opinion that some factors, as capital (in its different forms) accumulation and technological progress, are crucial (maybe more important than others) in order to promote growth in the long-run is widely spread among macroeconomists. In the following discussion we will focus on some of these factors and how they are related to the growth debate. We will consider population growth, technological progress and sustainability. The choice of these issues is driven by their growing importance in the analysis of the development process of modern economies in the real world.

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2 Technological Progress

During the last century, the development process of industrialized countries has been characterized by consistent growth, and different variables have been identified as the underlying causes of such an outcome. Firstly, Solow (1965) focussed on the accumulation of physical capital in order to explaining growing economies; then, Lucas (1988) considered the evolution of human capital as the main engine of growth in the long-run; recently, Romer (1986, 1990), read the production and accumulation of ideas as the central element of modern growth processes. One can therefore wonders what is the relationship between such different variables and in order to answer such a question we need to construct a model able to encompass all of them in a simple and tractable framework.

The best candidate to do this is a multi-sector context á-la Lucas-Uzawa (1988), extended to allow endogenous creation of knowledge. Without discussing in detail the model (if interested, see La Torre and Marsiglio, 2011), this can be summarized by the following dynamic problem, in which the planner seeks to maximize the total discounted ($\rho > 0$ is the subjective discount rate) sum of utilities (assumed to be iso-elastic) of the representative household, subject to the laws of motion of physical, K, human, H, and technological (knowledge), A, capital[1], and the initial conditions $K(0)$, $H(0)$, $A(0)$:

$$\max_{\{C_t,u_t,x_t\}_0^\infty} \quad U = \int_0^\infty \frac{C_t^{1-\sigma}-1}{1-\sigma} e^{-\rho t} dt \tag{1}$$

$$s.t. \quad \dot{K}_t = K_t^\alpha (u_t H_t)^\beta A_t^{1-\alpha-\beta} - C_t \tag{2}$$

$$\dot{H}_t = (1 - u_t - x_t) H_t \tag{3}$$

$$\dot{A}_t = (x_t H_t)^\phi A_t^{1-\phi} \tag{4}$$

In order to maximize his objective function, the planner needs to determine consumption, C, and the share of human capital to allocate to physical production, u, and to knowledge creation, x. Notice that the production function in each sector shows constant returns to scale.

It is possible to show that the economy converges towards its unique non-trivial steady state equilibrium, along a multi-dimensional saddle-path. In particular, both the stable and unstable manifolds result to be multi-dimensional, meaning that the convergent trajectory is not uniquely determined. The main implication of this is that during the transition the economy can show monotonic, non-monotonic or even cyclical behavior. Therefore, relatively little is known about how we can foster economic growth in this framework and how different policy tools affect the interaction between physical, human and technological capital. If we want to develop a positive approach, we need to isolate some of these variables, facing the risk of oversimplifying the reality.

3 Population Growth

Which is the role of population growth on economic development is an old debate, dating back even to Smith and Malthus. After two hundred years of studies, a shared view on the issue has not arisen yet. One view considers population as a fuel for growth (Jones, 2001), another one thinks it is a threat for the economy (Barro and Becker, 1989) and a further view exists saying that it has no implications with it at all (Bloom et al., 2003). Therefore, understanding how and through which channels demography affects the economy is particularly important in macroeconomics, since this is linked to the notion of social welfare function. The most discussed welfare criteria are based on utilitarianism, both in its average and total forms which, respectively, say that social welfare coincide with per capita welfare and the sum of per capita welfare across

[1] Abstracting from depreciation, physical capital accumulation depends on the difference between physical production and consumption, while human and ideas accumulation simply coincide, respectively, with the production of new human capital and new knowledge.

the society (see Marsiglio, 2010). In an homogenous agents framework, both the utilitarian approaches can be represented by the following function:

$$W = u(\cdot)N^{1-\epsilon},$$

where $u(\cdot)$ is the individual utility function and $N^{1-\epsilon}$ is the population size, N, weighted by the degree of altruism towards future generations, $1-\epsilon, \epsilon \in [0,1]$. Notice that $\epsilon = 0$ ($\epsilon = 1$) corresponds to total (average) utilitarianism.

A natural question is whether and how a different type of welfare function affects the economic growth rate, and the best setup to analyze such issue is an optimal two-sector endogenous growth model (see Marsiglio and La Torre, 2011), which can be summarized by the following problem:

$$\max_{c_t,u_t} \quad \int_0^\infty \frac{c_t^{1-\sigma}}{1-\sigma} N_t^{1-\epsilon} e^{-\rho t} dt \tag{5}$$

$$s.t. \quad \dot{K}_t = K_t^\alpha (u_t H_t)^{1-\alpha} - N_t c_t \tag{6}$$

$$\dot{H}_t = (1-u_t)H_t \tag{7}$$

$$\dot{N}_t = N_t g(N_t) \tag{8}$$

in which the planner maximizes[2] the social welfare (as just discussed) subject to the laws of motion of the economy (represented by the evolution of physical, K, and human, H, capital) and population, and the initial conditions $K(0)$, $H(0)$, $N(0)$, by choosing average consumption, c, and the share of human capital to employ in physical production, u.

If demographic growth is exogenous, a unique non-trivial equilibrium exists and the economy converges towards it along a saddle path, independently of population dynamics. What is affected by the features of the population growth function is the dimension of the stable arm, which can be one (uniqueness of the converging path) or two. Moreover, if a stationary population level exists (as claimed by several studies, see Brida and Accinelli, 2007) then no difference between average and classical utilitarianism will arise; if instead population can freely (and positively) grow without any bound, then total utilitarianism leads to higher economic growth than average utilitarianism.

If the altruism is impure, and it equals both the capital share and the inverse of the intertemporal elasticity of substitution, $\epsilon = \sigma = \alpha$, the whole transitional path of the economy can be fully characterized even in the case population is subject to random shocks. Assuming that demography evolves according to a geometric Brownian motion, as in Smith (2007), it possible to show that uncertainty on the population level increases on average the levels of both per-capita physical and human capital.

4 Sustainable Development

Sustainable development is that kind of development that *"satisfies the needs of the present without compromising the ability of future generations to meet their own needs"* (World Commission on Environment and Development, WCED, 1987). How combining this definition of sustainability (the most diffused and widely accepted definition) with the mathematical needs of optimal control theory, and therefore, of growth theory is an open question. The origin of such a problem lies in the evaluation of intertemporal welfare, and several ideas have been proposed in the literature (Chichilnisky et al., 1995; Chichilnisky, 1997; Pezzey, 1997, Arrow et al., 2004), but none seems to be very useful for growth economists.

The simplest framework to analyze this issue is a Ramsey-type model extended to environmental assets, as in Chichilnisky et al. (1995). The planner problem consists[3] of maximizing (total) welfare subject to

[2] As before, we abstract from depreciation and we assume that the utility function is iso-elastic. The dynamics of population instead depends on a generic function $g(\cdot)$ of population size.

[3] Again, we abstract from depreciation and we assume that the utility function is iso-elastic in its arguments, consumption and environmental stock.

the law of motion of demography and environment, E, and the initial conditions $E(0)$, $N(0)$, by choosing average consumption and fertility rate:

$$\max_{c_t,n_t} \quad W = \int_0^\infty \frac{(c_t E_t^\beta)^{1-\sigma}}{1-\sigma} N_t e^{-\rho t} dt \tag{9}$$

$$s.t. \quad \dot{E}_t = rE_t - N_t c_t - a n_t^b E_t \tag{10}$$

$$\dot{N}_t = (n_t - d)N_t. \tag{11}$$

Population evolves according to the difference between birth, n, and death, d, rates and the environmental capital to the difference between its renewal capacity (linear), consumption and a (non linear) dilution function representing the demographic pressure on the environment.

If we define a sustainable path as a paths along which all economic variables are (strictly) positive and also asymptotically (strictly) positive (see Marsiglio, 2011), we can obtain a simple and weak definition of sustainability compatible both with the WCED notion and the macroeconomic needs. Notice that such a definition simply requires that the economy, demography and environment find a way to coexist.

In this framework, it is possible to prove that even adopting an optimistic view on natural resources (they give rise to perpetual growth) and a weak notion of sustainability (non negativity of the main variables), the existence of sustainable trajectories is not certain, and therefore public intervention plays a crucial role in order to address the economy along a sustainable path. Moreover, this definition of sustainability leads to a realistic result in the sense that allows us to distinguish between sustainable and not sustainable paths within the same framework. Other comparable notions of sustainability instead do not permit the same comparison: Arrow et al. (2004) defines as sustainable a path along which welfare is non-decreasing over time, while Pezzey's (1997) define as survivable a path characterized by a welfare level higher than the minimal welfare allowing the survival of the current population. At equilibrium, the welfare is decreasing over time, because of the necessity of ensuring the boundedness of objective function: this means that according to Arrow et al. (2004) formulation, no path is sustainable; moreover, if the minimal survival welfare is sufficiently low (high), then the steady state welfare level will always be higher (lower) than this: according to Pezzey's (1997) notion, all paths (no paths) are sustainable.

5 Conclusion

The models presented here analyze just three different issues related to economic growth. As it may be clear, such topics are strictly interrelated: population growth affects technical progress (by providing an higher number of researchers), technical progress affects the environment (by leading to clean production technologies), and the environmental quality affects population growth (through its impact on health). These aspects are not considered in these models, but we will need to deeply investigate such mutual implications if we want to clearly understand how fostering growth of real world economies. More work is therefore needed in order to meaningfully answer Lucas's (1988) questions and we leave further explorations along this line for future research.

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