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Phases of economic development and the transitional dynamics of an innovation–education growth model

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ABSTRACT

This paper extends earlier analysis of the transitional dynamics of a growth model in which both human capital and innovation drive income expansion. Funke and Strulik [2000. On endogenous growth with physical capital, human capital and product variety. European Economic Review 44, 491–515] suggest that the typical advanced economy follows three development phases, characterized in a temporal order by physical capital accumulation, human capital formation, and innovation, and that the transitional dynamics of the model reproduce such a sequencing. I argue that other sequences of the phases of development are possible and show that the model can generate a trajectory in which innovation precedes human capital formation. This trajectory accords with the observation that the rise in formal education followed with a considerable lag the process of industrialization. U.S. income and educational time series data are used to corroborate the innovation–education trajectory.

1. Introduction

Funke and Strulik (2000) provide a formal framework to integrate two separate lines of research on economic growth. One strand of research, inspired by the seminal contributions of Uzawa (1965), Lucas (1988), and Rebelo (1991), is based on the premise that the spectacular growth record of modern economies is due to investment in human capital. The other, which builds on the influential work of Romer (1990), Grossman and Helpman (1991), and Aghion and Howitt (1992), among others, posits that the chief driving force of economic development is technical change resulting from innovative activities carried out by profit-maximizing agents.

Funke and Strulik (2000) (henceforth FS) argue that not only are the two views compatible with each other, but they can be merged into a unified theory to give a more profound understanding of the process of development. Their conjecture is that an economy's first stage of development is characterized by physical capital accumulation, as emphasized for instance in the Cass-Koopmans (CK) model. Here, growth occurs only as long as the capital–labor ratio keeps rising. Only when the economy enters a second stage of development characterized by human capital accumulation does long-run sustained growth become possible. They use the Lucas–Uzawa (LU) model to describe this growth stage. In the third and most sophisticated phase of development, both human capital formation and innovation are present. A product variety expansion growth model, as exemplified in Grossman and Helpman (1991), is merged with a Lucas–Uzawa model to capture this stage of development.

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My objective is to show that FS's framework is capable of generating a richer set of development scenarios. Specifically, I will claim that it can account for one in which the sequencing between human capital formation and innovation is reversed. This is more than a mere theoretical possibility. Historically, many modern economies have known a prolonged period of technological progress *before* investing in education. Perhaps the most notable case is that of England. At the onset of the Industrial Revolution in the middle of the 18th century, not only the average worker, but also the great captains of industry, were illiterate. Indeed, the extraordinary flow of innovations in Britain during the Industrial Revolution was not preceded by any noticeable expansion in formal education. A significant increase in British primary education occurred only in the second half of the 19th century—long after the acceleration in the rate of income growth (Clark, 2005) and the onset of modern industrialization. A similar sequence of events took place in Western European countries and the United States. The expansion of higher education, which, arguably, has contributed more significantly to the rising efficiency and productivity of labor, is a relatively modern phenomenon. In developed economies, enrollment rates in tertiary education have surged only in the post-war period. Before WWII, enrollment rates were only 2% of the relevant cohort in all countries for which we have data, with the exception of the United States, where that level has already been reached in the 1920s. Recent data show that the participation rate in developed countries is above 40% of the cohort and about 20% worldwide (Schofer and Meyer, 2005). Hence, if human capital is interpreted as the result of investment in formal education, a stylized sequence to be explained is one in which the rise of education follows the introduction of new production techniques.

The exposition continues as follows. The next section summarizes the model and derives the firms' and representative consumer's optimal conditions. The aggregate dynamics of the economy for interior and corner solutions are described in Section 3. Section 4 compares, through numerical analysis, alternative development sequences. Section 5 concludes.

2. Summary of the model

In this section, I summarize FS's model and derive the differential equations that describe the dynamics of the economy. A detailed discussion of the existence of manifolds and steady state equilibria can be found in FS and Arnold (2000). The economy has a constant population of measure one. Each individual is endowed with one unit of time. Final output is produced according to a Cobb–Douglas function

$$y = a_1 k^{\beta} d^{\eta} (hu_P)^{1-\beta-\eta},$$

where a_1 is a positive constant, β and η are positive elasticity parameters whose sum is smaller than one, k is physical capital, h denotes the worker's level of skills, u_P is the amount of time allocated to production, and d represents an aggregate index of intermediate goods. Specifically, $d = [\int_0^n x(i)^{\alpha}]^{1/\alpha}$, where $x(i)$ is the quantity of intermediate good (i) and n is the variety index. Intermediate goods are embodied in the final product—that is, they depreciate completely with one cycle of production. The parameter α is positive and smaller than one. Let r, p_D, and w be the rental price of k, the cost of purchasing one unit of d, and the wage rate per unit of human capital, respectively. The first order conditions imply that: $r = \beta y/k$, $p_D = \eta y/d$, and $w = (1-\beta-\eta)y/hu_P$. Intellectual property rights, first-move advantage, technological leadership, or a combination of these circumstances imply that the intermediate good i is priced in a monopolistic market, namely $p = 1/\alpha$—the marginal cost of one unit of intermediate good is one unit of consumption good, and there are no fixed costs. It follows that $p_d d = pnx$. This condition combined with one of the first order conditions implies $pnx = \eta y$. Consequently, the profit of an intermediate good firm is $\pi = (1/\alpha - 1)\eta y/n$. Since $x = \eta y/pn$ and $d = n^{1/\alpha}x$, a reduced form of the final output production function is

$$y = a_2 k^{\beta/(1-\eta)} n^{(1/\alpha-1)\eta/(1-\eta)} (hu_P)^{(1-\beta-\eta)/(1-\eta)}, \tag{1}$$

where $a_2 = [a_1(\alpha\eta)^{\eta}]^{1/(1-\eta)}$.

The technology for human capital accumulation is

$$\dot{h} = \xi u_E h, \tag{2}$$

whereas that for innovation is

$$\dot{n} = \delta u_I h, \tag{3}$$

where ξ and δ are positive productivity parameters and u_E and u_I are the time an individual allocates to education and innovation, respectively. A dot on a variable denotes time derivative.

Preferences are represented by $(c^{1-\theta}-1)/(1-\theta)$, where c stands for consumption and θ governs the intertemporal elasticity of substitution. The representative individual optimizes an intertemporal utility function under the usual dynamic asset constraint, the time constraint $u_P = 1 - u_I - u_E$, and the two constraints contained in Eqs. (2) and (3). The current-Hamiltonian is

$$\frac{c(t)^{1-\theta}-1}{(1-\theta)} e^{-\rho t} + \lambda(t)[w(t)(1-u_E(t)-u_I(t))h(t) + \delta u_I(t)h(t)v(t) + r(t)a(t) - c(t)] + \mu(t)\xi u_E(t)h(t),$$

where the variable t refers to time (it will be dropped from here on), λ and μ are shadow values, a denotes assets, and v is the market value of an innovation. Let u_I, u_E, and c be the choice variables and a and h be the state variables, and let g_x denote x's growth rate. The household's internal solution to the above problem (one in which u_I, u_E, and c are positive)