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Human capital accumulation in R&D-based growth models

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ABSTRACT

This paper develops a model that reproduces the essential aspects of the recent ICT-based economy using the framework of endogenous growth theory in which a central role is played by human capital accumulation. In particular, it considers a multi-sectoral growth model in discrete time with infinite horizon, endogenous growth, embodied technological progress, horizontal differentiation and “lab-equipment” specification of R&D, and with human capital accumulation (represented by the fact that households devote a fraction of their time to schooling), in order to take into account the crucial role of the latter when new technologies are present. In this model it is possible to obtain some important results, both analytically and through simulations, either in the case of constant productivity of schooling and in the case in which this productivity is a function of technological progress. The first conclusion is that the productivity of schooling affects the long run growth of the economy, contrary to the productivities of the other sectors, hence in this model human capital accumulation is the true engine of growth. It is then possible to study the reaction of the economy to different types of shocks, and to compare the results with the empirical evidence. The conclusion is that the model is able to reproduce such evidence, suggesting that the interaction between ICT and human capital is one of the drivers of the recent economic performance.

1. Introduction

This paper presents a multi-sectoral endogenous growth model, that is able to reproduce the most important aspects of an “ICT-based economy”, in which a central role is played by human capital accumulation, extending a previous analysis developed in Mattalia (2002). Indeed, one of the characteristics of the so-called “New Economy” is that human capital can be of great importance, since education is crucial in acquiring the knowledge necessary to use the new technologies, and at the same time an increase in ICT makes it easier to accumulate human capital. For this reason, the adoption of new technologies has often coincided with growing needs in human capital, reflecting the complementarity between these two forms of investment in the production process. There is also a relationship between human capital (i.e. the skills and competencies embodied in workers) and labour productivity, so that improvements in one lead to increases in the other, and therefore human capital is a significant determinant of economic growth. According to recent studies, for example, in OECD countries, one additional year of schooling would, on average, lead to about 6% higher GDP in the long run (OECD, 2000). The productivity-enhancing role of human capital is due to its complementarity with new technology (ICT use requires skills and competencies), and for this reason the demand for knowledge-intensive employment has risen considerably. In effect, in the 1990s, knowledge workers (including computer workers) were the fastest-growing occupational category in the US and the EU area (the average annual change in 1992–99 was 3.3%). In the US the ICT workforce reached more than 6.5 million in 2000, with almost 60% of these workers employed in high-skilled ICT occupations, 25% in medium-skilled jobs and the remaining in low-skilled occupations. From 1995 to 1999, the percentage of computer workers with respect to total employment in the US raised from 1.8% to 2%, furthermore employment growth has been strong throughout 2001 and unemployment rates in ICT professions very low. With reference to the contribution of human capital to economic growth, then, recently it has been observed a shift of labour demand towards high-skilled workers, together with growing ICT skills shortages. In addition, the distribution of high-skill and low-skill ICT-related occupations in the US and the EU shows an interesting pattern, in fact although the share of ICT workers is growing everywhere, in 1999 the US ICT workforce appeared to be relatively more high-skilled (77%) than that of the EU (56%). High-skill ICT workers are the most rapidly growing component of high-skilled workers and in 1999 they represented 2.4% of total employment in the US and 1.6% in the EU. In 2000 the US employed about 5.5 million persons in the ICT sector, and this sector has been a major source of employment growth, in fact over the 1995–2000 period OECD-area employment in the sector grew at an average annual growth rate of over 4% (almost 3 times that of overall business sector employment), and the proportion of ICT specialists has risen between 1995 and 2004 (see OECD, 2005).

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Another indicator that can be used as a proxy of the level of human capital of a nation is represented by the share of the population that has attained qualifications at the tertiary level (indeed, this can be considered a key indicator of how well countries are placed to profit from technological and scientific progress). Table 1 reports some statistics concerning this aspect (see OECD, 2008) and it turns out that OECD countries have seen significant increases in the proportion of the adult population attaining tertiary education over the last decades. In 1992, for the 25–64 year-old population, the OECD average of the population having attained the tertiary level was 19%, while in 2005 the average increased to 26%. US performed remarkably high, and the corresponding percentages were 30.2% in 1992 and 39% in 2005. Furthermore, in the youngest age group, 25 to 34 years old, the OECD country mean for tertiary attainment increased from almost 22% to over 32% between 1992 and 2005 (and in three countries – Canada, Japan and Korea – 50% or more of this age group had in 2005 obtained a tertiary qualification).

Human capital includes not only the education workers bring to the job, but also skills learned while working and adapting to new technologies. In particular, training plays a significant role when technological change is rapid and the knowledge necessary to implement the new technologies is very specific. For example, a number of studies referred to Canada have established that the implementation of new technologies in manufacturing firms increased the level of required qualifications and stimulated firms to invest in training (Baldwin and Peters, 2001; Baldwin et al., 1997). Other researches relative to the US have also shown that highly educated workers are more likely to participate in training than those with little education, suggesting a complementary relationship between human capital acquired through the education system and that acquired through in-house training (Bartel and Sicherman, 1998; Leonard et al., 2003; Lynch, 1992). However, further studies have shown that the participation differentials in training between workers with little education and those who are highly educated are mitigated when there is a high rate of technological change (Turcotte and Rennison, 2004). These studies also conclude that investments in education, training and new technologies are closely related, and are associated with higher productivity.

These researches are in line with recent theoretical and empirical advancements in the endogenous growth literature, according to which not only R&D activity, but also human capital accumulation, is a primary determinant of economic growth. For these reasons, the model presented in this paper studies the role of R&D and of human capital accumulation in the growth process that has characterised the ICT revolution. More precisely, this model extends the one proposed in Mattalia (2002), and introduces the choice of the households to invest in human capital, by devoting a fraction of time to schooling activity. This human capital accumulation, then, turns out to be the true engine of growth of the model, that therefore has important differences with respect to the one presented in the previous paper. In particular, in this case it is possible to obtain explicitely (in the benchmark version) the growth factors of the different variables, contrary to the previous model, where it was possible to obtain only a parameterized solution. The most important contribution, then, is represented by the fact that in its more general formulation the model studies the ICT productivity-enhancing role in education, considering the productivity of human capital (i.e. of schooling) as a function of technological progress, that specifies the complementarity between human capital accumulation and technological progress (since new technologies can allow people to be more educated). In this case the different growth factors and the different long run levels can be found only numerically (and not analytically as in the benchmark version with constant productivity of human capital). This is the true novelty of this model with respect to the existing literature, and represents a very important contribution.

Table 1
Tertiary attainment for age group as a percentage of the population of that age group.

	Age group 25–64		Age group 25–34	
	1992	2005	1992	2005
United States	30.2%	39%	30.2%	39.2%
OECD average	19%	26%	21.9%	32.2%

Source: OECD Factbook (2008).

The analytical study of the model allows to find some results concerning the effects on growth of different shocks that can interest the economy, and that can be compared with the available data. These results show in particular that permanent changes in the productivity of the final good sector, in the productivity of the equipment sector and in the productivity of the intermediate good sector do not affect the long run growth rate of the economy (contrary to what happens in the model of the previous paper), while it is affected by the productivity of schooling (that in this case is the true engine of growth).

Resorting to numerical simulations it is then possible to obtain other insights. In particular, it is possible to study how the economy reacts, in the short run, to shocks on the productivities of the different sectors. With reference to this aspect it turns out that an increase in the productivity of the final good sector and a decrease in the cost of a new variety of software, on the one hand, and an increase in the productivity of the equipment sector and an increase in the productivity of the intermediate good sector, on the other hand, have similar consequences. We also have that considering the more general version of the model with productivity of schooling depending on technological progress, the short run behaviour of the variables is different with respect to the benchmark model in which the productivity of schooling is constant.

The paper is organized as follows. Section 2 describes the model with the different sectors that characterize the economy. Section 3 derives the equilibrium conditions, the balanced growth path and the steady state system, with the corresponding analytical results. Section 4 shows the results of numerical simulations on a calibrated version of the model and compares these results with the available data regarding in particular the US. Section 5 concludes, while all the computations are available in a separate Appendix.

2. The model

The model presented here builds on Romer (1990) and Boucekkine and de la Croix (2003) for the general structure, but departs from them in some respects. It is a multi-sectoral model written in discrete time with infinite horizon, endogenous growth and horizontal differentiation. The economy is characterized by 4 sectors: the final good sector, the equipment sector, the intermediate good sector and the R&D sector. Technological progress is mainly embodied (the idea is that new softwares need new hardware to work efficiently) and the innovators have a market power represented by copyrights. All these elements are important to reproduce the essential characteristics of the ICT sector. Moreover, the R&D sector assumes the "lab-equipment" specification (first introduced by Rivera-Batiz and Romer, 1991), and a human capital accumulation activity of the kind introduced by Lucas (1988) is considered (assuming, in addition, in the more general version that the productivity of human capital is a function of technological progress). The reason is that, together with the embodied nature of technological progress, the important role of the R&D sector and the link between innovation and market power (all elements that are present in the model introduced in Mattalia, 2002), an ICT economy can be characterized also by an important role of human capital accumulation (for the reasons cited in the Introduction). With reference to this aspect, we have that, despite this importance, it is not assumed that the R&D sector is more intensive in human capital than the final good sector (essentially for algebraic convenience); in any case it turns out that human capital