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# Embodied Technological Change and Technological Revolution

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## 1 Introduction

At the beginning of 2000s the sector of Information and Communication Technologies (ICT) has been considered of fundamental importance in the explanation of the economic performance of several countries.

The analysis of the data shows that labour productivity growth continued to improve over the 1990s (in effect in the US the average growth of 2% per year over the decade 1990-2000 has been determined by an average growth of 1.3% per year in 1990-95 and of 2.5% per year in 1995-2000) and that multi-factor productivity has been characterized by a structural improvement from the 1980s to the 1990s. In particular, the strong productivity growth registered in the computer sector (i.e. in the production of hardware) has led some analysts to conclude that the era of a “New Economy” has begun, a sort of “Third Industrial Revolution” in which information and communication technologies can be compared with the great inventions of the past that characterized the traditional Industrial Revolution. On the other hand, more sceptic analysts consider this phenomenon as nothing more than a stock market bubble, whose economic benefits will in the end be of negligible importance.

For all these reasons a great attention has been devoted, both from an empirical and from a theoretical point of view, to the study of what has been called the “ICT Revolution” and of its effects on the economy.

On the empirical side, the main studies (Gordon, 1999, 2000; Jorgenson and Stiroh, 2000; Oliner and Sichel, 2000; Whelan, 2000) outline the strong productivity growth in the computer sector (particularly in the years 1995-1999, with an increase of about 42% per year), but evidence also problems of measurement of the real contribution of ICT to the growth and productivity of the economy, together with the fact that the productivity growth in the computer sector has not been accompanied by spillovers from this sector to the rest of the economy. Therefore, there are reasonable doubts about the long-term viability of the ICT-driven economic expansion.

On the theoretical side, the most important contributions (Greenwood and Yorukoglu, 1997; Greenwood et al., 1997; Greenwood and Jovanovic, 1998, 1999; Hobijn and Jovanovic, 1999; Jovanovic and Rousseau, 2000) underline the importance of embodiment of technological progress (i.e. the fact that only the new machines incorporate the latest technological advances), but underline also the fact that the ICT revolution has been accompanied by some “puzzling phenomena”. In particular, on the real side there has been an initial strong decrease in the productivity of the whole economy (the so-called

“productivity slowdown”) immediately after the beginning of the ICT revolution (in the early ’70s), followed only later by a rise (in the late ’90s the rise of productivity in the computer sector has been larger than 40% in the US).

The main explanations that have been proposed are based on the idea that the initial drop in productivity is due to an adoption period of the new technologies (because the pre-existing firms are not able to use immediately these new technologies at their full potential); this period is characterized by learning costs and slow diffusion (and it is precisely in this phase that the “productivity slowdown” takes place), and it is followed by an age of maturity during which the ICT sector starts driving the whole economy.

## 2 The model

A different view is taken by Boucekkine and de la Croix (2003), that argue the possibility of explaining the essential characteristics of the ICT revolution in the framework of endogenous growth theory (considering endogenous embodied technological progress), and to obtain indications regarding the determinants and the long term viability of an ICT-driven economic expansion. In particular, they consider the effects of positive supply shocks (especially in the hardware and in the R&D sectors, according to the recent empirical literature of the digital revolution), and they find that only a positive productivity shock in the R&D sector has long term growth effects (while a similar shock in the capital sector is unable to produce similar effects). As a consequence, only if the ICT-driven growth episode is based on an increase in the productivity of R&D it is possible to conclude that this expansion is likely to have permanent effects in the economy.

The model presented in this paper is based on the contribution of Boucekkine and de la Croix, and tries to explain some characteristics of the ICT revolution that emerge from the data, in particular the behaviour of output growth as a consequence of productivity shocks linked to the introduction of new technologies. It is a multi-sectoral endogenous growth model (of Romer’s type, 1990, in order to capture the R&D effort of the firms operating in the ICT sector) and it reproduces some of the essential characteristics of the ICT-based economy, in particular the embodied nature of technological progress (since the technological innovations that characterize the ICT sector are typically embodied in the new capital goods), the preeminent role of the R&D sector (since the amount of resources devoted to research is particularly high, especially in the US), and the link between innovation and market power (since ICT markets are typically non-competitive).

The crucial differences of this model with respect to Boucekkine and de la Croix concern the composition assumed for the workforce and the specification adopted for the R&D sector. Indeed, the present model assumes a homogeneous workforce (without distinguishing between skilled and unskilled workers) and the so-called “lab-equipment” specification (first introduced by Rivera-Batiz and Romer, 1991) for the R&D sector.

The model considers discrete time with infinite horizon, endogenous growth and horizontal differentiation and the economy consists of 4 sectors (together with the representative household, that consumes, saves for future consumption and supplies labour):

- **the final good sector:** it produces a composite good (used to consume or to invest) using efficient capital (bought from the equipment sector) and labour;

- **the equipment sector:** it produces efficient capital (sold to the final good sector) using physical capital (hardware) bought from the final good producers and immaterial capital (software) bought from the intermediate good producers;
- **the intermediate good sector:** it produces immaterial capital (software), sold to the equipment sector, using only labour;
- **the R&D sector:** it researches for new varieties of immaterial capital, in order to expand their range (horizontal differentiation).

In this model technological progress is mainly embodied (the idea is that the new softwares can only be run on the most recent hardware) and the innovators have a market power represented by copyrights, in order to stimulate innovation (that corresponds to an expansion in the varieties of softwares that are available) and growth. All these elements are important to reproduce the essential characteristics of the ICT sector.

The optimality conditions that hold at the equilibrium are derived, then the balanced growth path and the steady state are obtained, and in this way it is possible to find some analytical results concerning the effects on growth of different shocks that can interest the economy. It is then possible to consider the numerical simulation of a calibrated version of the model, that allows to obtain interesting results concerning the short run response of the system to the shocks and the robustness of the model. These results are also compared with the available data concerning the US, in order to verify the ability of the model to reproduce the real situation.

### 3 Main results

The first result obtained is that the “lab-equipment” specification assumed for the R&D sector allows growth as a consequence of productivity shocks in all sectors (final good sector, equipment sector, intermediate good sector, R&D sector). The presence of the “lab-equipment” assumption, therefore, changes the implications of the model as a consequence of shocks with respect to the original version, without such assumption. In the latter, in fact, only a shock on the productivity of the R&D sector influences the growth of the economy in the long run.

A second result is that, in the present model, the shocks on the productivity of the final good sector and on the cost of R&D on the one hand, and the shocks on the productivity of the equipment sector and of the intermediate good sector on the other hand, affect differently, in the short run, the economy, and influence the growth with different intensity. Interestingly, the intensity of growth, in the long run, as a consequence of these shocks is linked to the size (in terms of GDP) of the sector interested from the shock. More precisely, the effects on growth are stronger when the shocks concern the final good sector (that is very important, in fact more than 90% of the labour force is employed in this sector) or the R&D sector (that in this model is the true engine of growth), while they are weaker when the shocks concern the equipment sector or the intermediate good sector (that are less important, for instance the latter employes less than 10% of the labour force).

The model also turns out to be sufficiently robust, since when some parameter is significantly modified with respect to the benchmark case, both the qualitative and the

quantitative implications remain valid. Finally, an extension of the model that takes into account the presence of learning and spillover effects is able to reproduce empirically the behaviour of US productivity in the recent years.

The general conclusion that emerges from this model is that if the ICT revolution can be interpreted as a permanent shock on R&D or as a spillover (on the final good sector), it will have long run effects on the economy. On the contrary, if the ICT revolution is interpreted as a shock on the equipment sector or on the intermediate good sector (i.e. as the possibility of producing easily new softwares), it will not have strong long run effects.

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