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ICT as a general-purpose technology: The productivity of ICT in the United States revisited

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ABSTRACT

Researchers have long been puzzled by ICT's (Information and Communication Technology) contributions towards (productivity) growth. This paper investigates and reveals the multi-facets of ICT productivity and the mechanism through which ICT affects productivity by bringing all the distinct streams of existing findings together. In particular, we develop a two-level frontier-efficiency model to examine how ICT's direct and indirect impact on different components of productivity is related to the economic growth in the US. Our empirical analysis has confirmed that ICT investment does contribute to productivity but not in the usual manner – we find a positive (but lagged) ICT effect on technological progress. We argue that for a positive ICT role on growth to actually take place, a period of negative relationship between productivity and ICT investment together with ICT-using sectors' capacity to learn from the embodied new technology was crucial. In addition, it took a learning period with appropriate complementary co-inventions for the new ICT-capital to become effective and its gains to be realized. Our findings provide solid, further empirical evidence to support ICT as a general purpose technology.

1. Introduction

Many researchers attributed the impressive growth performance observed in the second half of the 1990 s in the US to rapid productivity growth and linked it particularly to ICT (Information and Communication Technology) investment which rose at a rate nearly double that of the preceding years (e.g., Cardona et al., 2013 and the references therein; Vu, 2013). For instance, Jones (2002) pointed out that the growth in output per hour and in multifactor productivity in the US rose substantially in the period of 1995–1998, returning about 50% of the way back to the growth rates exhibited before 1973. Most importantly, the increase in growth rates is partially associated with an increase in the use of IT, as this component of capital accumulation contributed only 0.1% points of growth before 1973, but by the late 1990 s, this contribution has risen to 0.8% points. Jorgenson et al. (2003) further shows that the growth rate of value added in the US has been raised by 1.85% when 1995–2000 is compared to 1990–1995, of which capital input contributes 1.02% to the post-1995 revival and a little more than half of this is due to the surge in IT investment; whilst faster growth in TFP (total factor productivity) contributes 0.40% and labour input contributes the remaining 0.44% to the growth resurgence. These figures and subsequent studies show the importance of ICT for economic growth and hence a deeper understanding of the role played by ICT in the US can potentially benefit other countries.

A widely accepted argument is that the rapid technological progress in the production of ICT and the induced accumulation of ICT capital raised productivity growth. This so-called "ICT-centred story" (Oliner et al., 2008) highlights the increasing importance of ICT as a driver of rising productivity and economic growth through direct TFP increase in ICT-producing sectors and through capital deepening and labour productivity improvement in ICT-using sectors (e.g. Jorgenson et al., 2003, 2008; Oliner and Sichel, 2000, 2002; Stiroh and Botsch, 2007; Inklaar et al., 2005). Despite this appealing argument, previous studies have also produced mixed findings on ICT's role in growth even with more rigorous analyses by subsequent researchers (for example, Gordon, 2000; Colecchia and Schreyer, 2002; Cardona et al., 2013).

Underlying the mixed results are three notable reasons. First, the majority of "ICT-centred story" papers consider the phenomenon within a neoclassical growth accounting framework and mainly at country level, treating ICT as an additional input on top of normal physical and human capital, but largely ignoring the

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possible diffusion effect created by ICT investment on TFP.[1] In other words, standard neoclassical growth theory states that the use of ICT can boost labour productivity in ICT-using sectors, but does not change TFP in sectors that only use but do not produce ICT. In this end, there is no reason to expect acceleration in the pace of TFP growth outside of ICT production. Among the most relevant and frequent findings of this line of research, we note limited relevant importance of ICT spillovers on TFP in various European countries, which is in sharp contrast to their effect in the US economy.[2]

Secondly, it has long been a research hypothesis in the literature that ICT is a general purpose technology (GPT), which is usually characterized as an enabling technology that induces further innovations and is adopted in a wide scope of sectors of an economy. Clearly, even though some evidence of ICT spillovers in the US can be observed, the productivity impact of ICT cannot be materialized until it reaches a critical mass of diffusion and experience. If ICT is indeed a GPT, then ICT-using sectors/firms learn from the embodied new technology with some "unobserved complementary co-invention" (Basu et al., 2003), and the resulting pace of technology adoption will be slower than is socially optimal. This so-called "ICT-related story" (Oliner et al., 2008) emphasizes the powerful connection between ICT and technology diffusion across sectors by seeking to establish the positive spillover effect of ICT on TFP in ICT-using industries. The contrast between these "ICT-centred" and "ICT-related" conceptualizations is illustrated in Fig. 1, from which we can see clearly that one channel operates by treating ICT as an additional input which could be potentially substitutable for the other inputs, while the other treats ICT as a complementary component of the management environment. Recent review in Cardona et al. (2013) shows that although ICT displays many GPT characteristics further and stronger empirical evidence is necessary. For example, there is no direct empirical evidence to show that a real time lag exists in the earlier ICT payoff studies, possibly due to the limitations of the methodologies in defining the underlying production technology, and some studies employed arbitrary numbers of years as the "lagged" time before the positive payoff from ICT investment (Basu et al., 2001, 2003; Bryjolfsson and Hitt, 1996). Hence, this represents an important research gap.

Thirdly, the mechanism through which ICT affects productivity growth, especially through efficiency enhancement, is not clearly explored. Traditional economic analyses of growth operate on the belief that there is full efficiency amongst firms, and the use of Solow's residual offers the ability of better measuring the productivity attributable to technology by using tangible outputs such as GDP, national wealth and revenue in the majority of earlier research. These output measures, however, might not capture the full contribution of ICT to an economy's productivity because the impact of ICT usage is generally considered to be wide ranging but intangible (Basu et al., 2007; Kleis et al., 2011). Alternative forms of productivity measurement, which provides more information about changes in technology are needed to better appraise the effectiveness of the use of ICT.

To address these research gaps, we will explore the multi-facets of ICT by adopting a frontier-efficiency approach and examining how ICT's direct and indirect impact on different components of TFP is related to economic growth in the US over the period of 1977–2005. Our research therefore aims to answer questions on what contributions to productivity the ICT investment has made in the recent decades, in what way, and what might be the reasons that some ICT-using sectors under-performed on the basis of efficiency analysis. As a result, this paper provides further empirical evidence for ICT as a new type of GPT.

The approach used in this paper differs from previous studies in a number of ways. On the conceptual side, intensive studies have examined the relationship between ICT and productivity in an economic growth context, from the perspective of GPT nature of ICT and organizational re-constructing due to appropriate/complementary ICT-knowledge (Jorgensen et al., 2003, 2008; Oliner and Sichel, 2000, 2002; Basu et al., 2003; Brynjolfsson, 1993; Brynjolfsson et al., 1996, 2000, 2002). However, individually focusing on one aspect rather than simultaneously considering ICT's multi-faceted impacts on productivity might yield mixed results – they can at the most uncover solely one aspect of ICT's impact and therefore might be conflicting to each other, or the overall result could show the combined/offset effects only with elusive findings arising from each individual aspect separately. By bringing the possible pieces of strands together into a single unified framework, it helps us unravel some puzzling phenomena reported in the published literature and therefore provides a better understanding of how various channels of ICT's impact work on productivity simultaneously.

On the methodology side, we develop a two-level stochastic frontier model which can accommodate both technological progress (TP) and technical efficiency change (TEC).[3] Existing stochastic frontier methods have some fundamental limitations that make it very difficult to fully understand the roles that ICT plays. First, they normally impose a pre-specified structure on the frontiers (e.g. a log-linear structure) so they cannot detect complicated nonlinear structural changes of the frontiers. Secondly, they usually assume a constant effect in the statistical model for inefficiency, hence are unable to capture the dynamic evolution of technical efficiency and to explore the reasons for its changes. We conjecture that the pre-specified structure on the frontiers could be one of the reasons that the existing literature fails to reveal the unusual nature of ICT, when viewed as a new GPT that differs from the traditional inputs we are familiar with. Another direct consequence of a mis-specified frontier structure is that the corresponding technical efficiency as part of TFP could be either under- or over-estimated, which will further lead to a biased analysis for efficiency. We show that the two-level stochastic frontier model developed in this paper does not impose any particular structure on the frontier functions, hence we are able to find the negative relationships between the productivity and ICT, if any, that were associated with the transition period. This new econometric model also leads to more accurately measured inefficiency for the production units of interest, which in turn provides us with an opportunity to investigate how technical efficiency evolves over time and also to explore what factors affect it.[4]

In a nutshell, our empirical analysis has confirmed that ICT investment does contribute to the productivity change but not in the usual manner – we find a positive (but lagged) effect of ICT on TP and positive effect of ICT on TEC over time. Moreover, for a positive ICT role on growth to actually take place, our findings show that

[1] This is because the traditional index number approach adopted in the existing empirical studies does not allow an unequivocal appraisal of the indirect effect of ICT on TFP, which has been recognized at the theoretical level by Helpman (1998).

[2] In contrast to the US, studies by Colecchia and Schreyer (2002) found that the ICT capital deepening contribution to aggregate labour productivity growth in Europe was only half of that in the US, mainly due to the much lower ICT investment levels in Europe, and the increase in ICT-investment, though, was not accompanied by a faster growth of TFP. To what extent this is due to a smaller ICT producing sector in Europe or to less productive ICT use is still not known.

[3] There are other studies that address ICT productivity issues with stochastic frontier model. For instance, Becchetti et al. (2003).

[4] We would like to thank one reviewer's comment that not all the typical problems associated with ICT productivity estimation can be solved by using the two-stage stochastic frontier approach and by relaxing the pre-assumed functional form, e.g. quality mis-measurement of capital and labour, unobservable factors (intangible capital) and endogeneity issues, etc.