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The modern drivers of productivity

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ABSTRACT

This paper studies the role of technology spillovers in productivity growth of OECD countries looking at investments in Information and Communication Technology (ICT) and Research & Development (R&D). We find that both forms of technologically advanced capital (ICT and R&D) influence total factor productivity (TFP) over the long run: the former effect derives from externalities related to the *use* of ICT capital, the latter from knowledge spillovers generated by research performed to *produce* ICT goods. These findings are robust to controlling for import penetration of ICT products and the underlying R&D. Our evidence suggests that: (i) investing in ICT capital delivers significant productivity benefits, (ii) domestic production of ICT goods is source of important knowledge spillovers, and that (iii) in terms of TFP gains a low degree of industry specialization in information technology cannot be compensated by a country's trade openness, i.e., by importing ICT goods. These results help to explain trends in high-tech specialization and international trade.

1. Introduction

The role of spillovers as a source of productivity benefits, and that of innovation as their enabling factor, are well-established topics in the literature. Innovation produces technological knowledge as output, and this can be used as an input in further research. Given its non-rival and non-excludable nature, knowledge spills over across space and time through various channels (trade, patents, people, etc.), yielding productivity gains that are proportional to the technological, geographical, or trade proximity between innovators and recipients. These externalities take place at any level of economic activity, i.e., among firms, industries, regions and countries (Keller, 2004).

Nowadays, it is debated which technologically advanced investments generate excess returns (R&D, human capital, intangibles, etc.), and which mechanisms promote dissemination of the underlying knowledge. Increasing attention has been paid to investment in tangible assets such as information and communication technology (ICT), either as a source of productivity spillovers or as a mean for knowledge diffusion.

The present paper contributes to this literature looking at two channels through which advances in new digital technologies may enhance aggregate total factor productivity (TFP).[1] Firstly, ICT leads firms to be better connected, manage (and exchange) more efficiently information and access a larger amount of external technological knowledge. ICT capital may therefore earn social returns greater than those accruing to direct users, and this reverberates on aggregate productivity as a positive spillover. Secondly, ICT producing firms generate a large volume of R&D-based knowledge that may spill over beyond industry boundaries. However, due to increasing international openness, TFP gains may also derive from R&D developed abroad and which is absorbed by domestic firms importing ICT goods.

ICT is one of the key forces behind the resurgence in labour productivity growth experienced by most Western countries since the 1990s. The growth acceleration in output per hour worked can be mostly explained by ICT capital deepening and TFP growth in ICT producing industries (Jorgenson, 2005). However, it is still unclear

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[1] TFP is defined as the residual component of GDP not directly ascribable to the use of factor inputs (capital and labour). See Solow (1957).

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whether (and how) new digital technologies are source of productivity spillovers at country level. This is a non-negligible lack of the literature as, conversely, there is strong evidence on productivity effects of ICT at firm level, and on spillovers from R&D even at higher levels of data aggregation. One possible explanation for the gap in the results of the ICT literature is that most works do not account for the long lapse of time before that productivity gains from ICT investment show up in aggregate statistics, as it typically occurs for general-purpose technologies (Jovanovic and Rousseau, 2005). From this perspective, looking at the long-run trend in the relationship between ICT and TFP may be helpful to understand whether these assets are source of spillovers and to identify the main channels of transmission.

Another crucial issue is whether ICT capital captures (embodied) spillovers associated with R&D carried out in the related technological fields. Identifying the impact of these two factors is, however, a controversial task. On the one hand, research raises the efficiency of the ICT producing sector, lowers the price of digital products, providing benefits to all purchasers of such goods. This represents a pecuniary spillover and does not necessarily imply that ICT users benefit from knowledge externalities deriving from the embodied base of R&D. The latter type of externalities materialise when firms exploit ICT-related knowledge to develop new products or production processes, and thus enhance their productivity levels. On the other hand, as yielding excess returns, ICT investment may generate spillover effects on TFP, and these differ from the ones stemming from R&D performed to develop new digital technologies. Thus far, only a handful of papers have considered the nature of productivity gains from ICT and R&D investments, their possible interplay, and the risk that such effects can be confounded. To establish whether excess returns are associated with the use of ICT capital, one has to control for the knowledge base developed in ICT productions, either at home or abroad.

The present paper addresses this issue pursuing a twofold goal of research. It primarily aims at verifying whether ICT capital generates aggregate productivity spillovers, or whether this factor does capture the impact of R&D-based knowledge associated with ICT production. Moreover, it questions whether trade of ICT goods is an effective conduit of the knowledge developed in related fields, so that a country can compensate a low specialisation on ICT production by importing these products. To this purpose, we develop an empirical framework able to conjugate the literatures on productivity spillovers from ICT and R&D, and estimate it by means of a long-run (cointegration) regression approach on a panel of OECD countries. As a first step, the elasticity of aggregate productivity to both forms of technological capital (ICT and R&D) is estimated within a closed-economy setup. Then, we examine the industry sources of within-country spillovers associated with R&D, focusing on the knowledge generated by the ICT producing industry. Lastly, analysis is extended to an open-economy framework, to trace spillovers related to international trade in ICT goods.

The work contributes to the literature in several respects. It provides new insights into productivity spillovers associated with the *use* of ICT assets, as well as knowledge (non-pecuniary) externalities enabled by the *production* of ICT goods. Furthermore, it increases understanding on patterns of high-tech specialization and international trade within the OECD area. Our evidence indicates that investing in ICT capital provides productivity gains unrelated to R&D undertaken in the areas of electronics or communication equipment. Nevertheless, in terms of productivity benefits, a wide use of ICT is unlikely to offset a low specialization in ICT productions. At the economy-wide level, TFP spillovers yielded by the knowledge developed in the ICT field originate from the research effort of domestic firms, as foreign knowledge cannot be easily absorbed through imports of ICT goods or micro-electronic components. The reverse occurs for the non-ICT producing industries for which trade is found to be an effective conduit of knowledge. These findings help explain the worldwide trends towards research concentration within high-tech (ICT) sectors.

The paper is structured as follows. Section 2 traces the empirical background. Section 3 defines the analytical framework and discusses some econometric issues. Data description and summary statistics are provided in Section 4. Econometric results are presented in Section 5. Section 6 discusses findings and concludes.

2. Overview of related literature

2.1. Productivity effects of ICT

In recent years, great attention has been paid to the *direct effects* of ICT to aggregate labour productivity growth, i.e., ICT capital deepening and TFP growth in ICT producing industries (Jorgenson and Stiroh, 2000; Timmer et al., 2010). These represent the growth contribution of ICT *usage* and ICT *production* and, together, accounted for the US lead in labour productivity growth over the EU since the mid-1990s (Timmer and van Ark, 2005). In the same vein, O'Mahony and van Ark (2003) investigate the sectoral sources of the EU-US productivity gap, finding its origins in the differential performance of the industries that *produce* or intensively *use* ICT assets (see also Inklaar et al., 2005).

At the country or industry level, econometric evidence remains ambiguous concerning the extent of TFP spillovers generated by these new technologies. For instance, Stiroh (1998) finds that computer investment did not affect US productivity growth until the early 1990s. Inklaar et al. (2008) report little evidence that ICT capital spurred TFP growth in US and EU market services industries, despite these are highly intensive users of ICT.[2] O'Mahony and Vecchi (2005) is one among the very few studies finding above-normal returns to ICT capital; however, this holds for the US but not for the UK industries. Overall, these findings contrast with the evidence provided by firm-level studies where large productivity increases are found to be associated with ICT investment (Brynjolfsson and Hitt, 2000).

The *indirect effects* of ICT typically take the form of network externalities and knowledge spillovers induced by better ideas circulation and information management (Fuss and Wavermann, 2005; Becchetti and Adriani, 2005). The lack of clear-cut evidence on ICT spillovers may reflect the nature of general-purpose technology of such capital goods (Bresnahan and Trajtenberg, 1995). The adoption of ICT entails a period of experimentation at firm level, during which business organization and the endowment of human capital need to be updated. Additionally, large adjustment costs may be associated with the replacement of old capital goods with new digital equipment (Kiley, 2001). The benefits of the adjustment finalized by first users also accrue to imitators and, at the aggregate level, the related gains show up only in the long run. It may explain why TFP growth is unrelated (or even negatively related) to the contemporaneous values of ICT investment, and positively with the lagged ones (Stiroh, 2002). Productivity improvements induced by ICT adoption may materialise with lags of 5–15 years, depending on the intensity of investment in complementary inputs or enabling factors. Conventionally, this is referred to as the *delay hypothesis* for the growth impact of ICT (Basu et al., 2004; Rincon et al., 2013).

2.2. Productivity effects of R&D

Since Griliches (1979) knowledge has been regarded as a key determinant of economic growth for the large spillovers on TFP.

[2] A focused analysis on the US service sector can be found in Triplett and Bosworth (2004).