Research Policy xxx (xxxx) xxx–xxx

Contents lists available at ScienceDirect

Research Policy

journal homepage: www.elsevier.com/locate/respol

Modelling the joint impact of R&D and ICT on productivity: A frontier analysis approach

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ARTICLE INFO

JEL classification:
O14
O32
O47

Keywords:
Research & development
Information and communication technology
Productivity
Stochastic Frontier Models

ABSTRACT

This study explores the channels through which technological investments affect productivity performance of industrialized economies. Using a Stochastic Frontier Model (SFM) we estimate the productivity effects of R&D and ICT for a large sample of OECD industries between 1973 and 2007, identifying four channels of transmission: input accumulation, technological change, technical efficiency and spillovers. Our results show that ICT has been particularly effective in reducing production inefficiency and in generating inter-industry spillovers, while R&D has raised the rate of technical change and favoured knowledge spillovers within sectors. We also quantify the contribution of technological investments to output and total factor productivity growth documenting that R&D and ICT accounted for almost 95% of productivity growth in the OECD area.

1. Introduction

What do we know about the drivers of productivity? What are the channels through which innovative investments translate into better productivity performance? The economic growth literature still debates which factors produce long-lasting effects on productivity and explain cross-country productivity differentials (Madsen, 2008; Cette et al., 2016). The latest theories of endogenous growth highlight the importance of innovation activities in raising the rate of productivity growth, and hence living standards, in the long run (Aghion and Howitt, 1998; Dinopoulos and Thompson, 1998). In the empirical literature, innovative activities, typically proxied by investments in Research and Development (R&D), have long played a major role in boosting productivity performance at the country, industry and firm level (Griliches, 1979, 1988; Patel and Soete, 1988; Guellec and Van Pottelsberghe de la Potterie, 2004; O'Mahony and Vecchi, 2009). Investments in R&D increase a country's competitive advantage, promote the international transfer of technological competences and intensify market competition, hence contributing to the growth of the so-called knowledge economy (Archibugi and Coco, 2005).

Since the mid-1990s, research has also focused on Information and Communication Technologies (ICT) and various contributions have shown that these assets are another important source of productivity growth in industrialized countries (O'Mahony and Vecchi, 2009; Venturini, 2009). ICT is often regarded as the main infrastructure of the knowledge (R&D-based) economy. However, the literature seldom considers its role next to the role of R&D (Polder et al., 2017). Exceptions include Hall et al. (2013) and Venturini (2015), who find that both ICT and R&D have positive but independent effects on Total Factor Productivity (TFP). Conversely, Corrado et al. (2017) document the presence of complementarities between ICT and intangible capital, which includes R&D and other innovative activities. Therefore, the empirical analysis so far does not provide a clear indication of the joint role of R&D and ICT or the different channels through which they affect productivity performance. The main objective of the present paper is to fill this important gap in the literature by investigating the productivity effects of both R&D and ICT and accounting for the possible ways in which these factors operate.

Thus far, the literature has analysed two main *channels* through which R&D and ICT can affect performance: *first*, an input accumulation channel, which focuses on the importance of capital deepening and on the productivity-enhancing effect of investments in knowledge assets. *Second*, a spillover channel, which recognises the possibility that technological investments promote the diffusion of knowledge across firms, both within the country and internationally (Coe and Helpman, 1995). The empirical evidence strongly supports the role of R&D as a factor of

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https://doi.org/10.1016/j.respol.2018.06.013
Received 27 November 2017; Received in revised form 25 June 2018; Accepted 27 June 2018

production and its ability to generate spillovers (Ugur et al., 2016). As for ICT, the evidence initially understated the extent of the input accumulation channel (Gordon, 2000), but a second wave of studies has documented that ICT is a significant driver of productivity growth (O'Mahony and Vecchi, 2005; Kretschmer, 2012).[1] The evaluation of the spillover potential for ICT has been more challenging. Stiroh (2002a) documents the absence of a relationship between ICT and TFP for the US, whilst Haskel and Wallis (2013) and Inklaar et al. (2008) provide similar evidence for European countries. Firm-level analysis is more supportive of the role of ICT spillovers, but contributions are still limited to single-country studies (Brynjolfsson and Hitt, 2003; Tambe and Hitt, 2014; Marsh et al., 2017).

A typical feature of this literature is the assumption that factor inputs are fully utilized and that there is no slack in production, i.e. all economic units are fully efficient (Greene, 2008). This assumption hides a potential *third* way in which R&D and ICT affect productivity, namely via their impact on technical efficiency, defined as the optimal combination of inputs to produce a given level of output. The evidence on the impact of R&D and ICT on production efficiency is sparse. Kneller and Stevens (2006) show that R&D investments affect the rate of technical change (i.e., they shift the production frontier outward) but they leave technical efficiency unchanged (i.e., they do not reduce the gap with the frontier). Bos et al. (2013) illustrate that R&D contributes to higher efficiency levels in mature industries, while it decreases efficiency in young industries. As for ICT, the General-Purpose Technology (GPT) literature has emphasised the link between new technologies and organizational changes (Jovanovic and Rousseau, 2005; Bresnahan and Trajtenberg, 1995). In fact, ICT has created opportunities for gathering and sharing information, both within and outside the firm, reducing administrative costs and improving supply chain management (Rowlatt, 2001; Criscuolo and Waldron, 2003). Hence, it is reasonable to assume that these developments contribute to a more efficient use of factor inputs within the production process. However, only a handful of papers have provided evidence in this respect. Becchetti et al. (2003) and Castiglione (2012) show that ICT investments reduce inefficiency in Italian firms. Papaioannou and Dimelis (2017) find a similar result at industry level but show that the effect of ICT is weaker in high-tech sectors. Using a cross-sectional sample of Italian companies, Bonanno (2016) relates both R&D and ICT investments to production efficiency, finding a positive effect for both technological assets.

Potentially, there is also a *fourth* channel of impact for R&D and ICT. These investments may expand the set of productive possibilities by enhancing the rate of technical change. Since the seminal work by Solow (1960), scholars have recognised that technical change may not be neutral but specific to firms' investments in new vintages of capital goods that embody the latest technologies (so-called investment-specific technical change). For example, Greenwood et al. (1997) illustrate that, in the US, the largest proportion of output growth is due to technical change embodied in machinery and equipment. Samaniego (2007) extends this analysis to investments in knowledge assets, finding that R&D-driven technical change is the main determinant of output growth. Venturini (2007) and Martínez et al. (2010) model the effect of ICT - specific technical change in promoting productivity growth in modern economies.

This paper investigates the impact of R&D and ICT on productivity performance, using a large panel data set covering fourteen countries and nineteen industries for the period between 1973 and 2007. Our analysis accounts for the four channels discussed above - input accumulation, spillovers, technical efficiency and technical change – within the same analytical framework. This relies on a Stochastic Frontier Model (SFM), which allows the joint estimation of the different channels, as well as the quantification of their contribution to productivity growth. Throughout the analysis we control for cross-sectional dependence, which may be induced by increasing globalization and multilateral interconnection through historic, geographic and trade relations (Mastromarco et al., 2016; Eberhardt et al., 2013).

Our results show that R&D and ICT increase productivity levels through different transmission mechanisms. R&D drives productivity through all the proposed routes, whilst ICT operates via investment-specific technical change and efficiency before 1995 and input accumulation after 1995. Our analysis provides evidence of important spillover effects associated with both R&D and ICT, and supports the presence of complementarities between R&D and ICT in reducing inefficiencies in production. In addition, we document that the nature of the efficiency impact of R&D changes with the technology intensity of production. Specifically, R&D investments have detrimental effects on efficiency in high-tech but positive effects in low-tech industries. Conversely, ICT raises efficiency levels in all sectors. Finally, we quantify that R&D and ICT investment contributed 95% of TFP growth in OECD countries, a result that unequivocally points to a key role for these technological assets in the knowledge economies.

This study relates to the literature on the drivers of productivity and the key sources of competitiveness in the global economy, offering important insights into the debate on the secular stagnation of productivity growth (Gordon, 2016; Jorgenson et al., 2016). We also contribute to those studies investigating whether returns to innovation change with technological opportunities and appropriability conditions (Terleckyj, 1974; Nelson, 1988; Ngai and Samaniego, 2011). Finally, our results add to the new literature on the impact of intangible assets on TFP growth, by detailing the transmission mechanisms via technical change and technical efficiency that have been largely unexplored to date (Corrado et al., 2017; Niebel et al., 2017). Hence, our analysis sheds light on how investments in intangibles, which include both R&D and computerized software among others, translate into greater productivity outcomes. Identifying the drivers of productivity growth and the different transmission mechanisms can be crucial for the design of policies aimed at improving growth performance (OECD, 2015).

The structure of the paper is the following. Section 2 draws the theoretical underpinnings of the link between R&D and ICT investments and productivity. Section 3 introduces our analytical framework, showing how ICT and R&D influence productivity performance within a SFM. Section 4 describes the data and presents a descriptive analysis. Section 5 presents the main results and discusses robustness tests. Section 6 quantifies the contribution of R&D and ICT to productivity growth and offers some insights for policymaking. Finally, Section 7 concludes the paper.

2. Background

The positive relationship between innovation and productivity performance is indisputable. Since the seminal works by Griliches (1958) and Evenson (1968), investments in R&D have been considered among the main drivers of TFP growth, i.e. the increase in output which is not accounted for by changes in labour and capital inputs. Many papers have concluded that R&D-based innovation yields positive effects on the productivity of innovators as well as on that of "related" firms/industries/countries in the form of knowledge spillovers (Mairesse and Sassenou, 1991; Sveikauskas, 2007; Ugur et al., 2016). R&D has also been considered one of the sources of absorptive capacity, which refers to the ability of companies to effectively benefit from the new knowledge created in neighbouring firms or industries (Griffith et al., 2004; Bos et al., 2010; O'Mahony and Vecchi, 2009).

Since the mid-1990s, the debate on innovation and productivity has concentrated on the new paradigm of the knowledge-based economy, which focuses on knowledge generating activities as the main source of firms' competitive advantage. The defining features of the knowledge-based economy are: i) a more systematic exploitation of knowledge by

[1] A recent contribution by Polák (2017) shows that the productivity effect of ICT may be lower than estimated in the post-1990s literature.