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ICTs and time-span in technical efficiency gains. A stochastic frontier approach over a panel of Italian manufacturing firms ☆

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ABSTRACT

In this paper, in contrast to much of the existing literature dealing with the impact of information and communication technologies (ICTs) on labour productivity, we assess the relationship between ICT investments and technical efficiency (TE) using a stochastic frontier approach. We utilize a large panel dataset of Italian manufacturing firms over the period 1995–2006 and confirm the findings of the previous work on ICT and productivity. In addition, we test to what extent ICT investments influence the gap between firms and the production frontier; that is, how adoption of ICT influences the narrowing of the said gap. We also test the duration of the effects of adopting ICT on technical efficiency. Finally, our results indicate that ICT returns on TE are influenced by certain firm characteristics, most of which idiosyncratic, such as management practices, labour organization, research and development.

1. Introduction

After a long debate on the returns of investment in information and communication technology (ICT) there is now a general agreement that ICT positively contributes to economic growth both at micro and macroeconomic levels. This debate has been largely based on the productivity paradox, which started soon after Robert Solow's (1987) statement: "You can see the computer age everywhere but in the productivity statistics".

The relevant empirical literature studies both the relationship between ICT investment and labour productivity, and ICT investment and total factor productivity (TFP). Yet few attempts have been made to study the relationship between ICT investments and technical efficiency (TE) at firm level (Becchetti et al., 2003; Castiglione, 2012; Mouelhi, 2009; Shao and Lin, 2001). The importance of this relationship arises from the fact that productivity growth is mainly the result of technical change and greater efficiency. Hence, it is important to verify the effect that ICTs have on both productivity and TE.

In this paper the Cobb–Douglas and Translog production functions are used to explore the impact of ICT investments on distance from the 'best practice technique'. We utilize the stochastic frontier model introduced by Battese and Coelli (1995). This methodology has the benefit of using a one-stage procedure to estimate both productivity and (in)efficiency. The paper adds to the existing literature in four ways. Firstly, ICT capital and high-skilled workers are considered as inputs in the firm's production function. Secondly, ICT investments are considered as a factor that can influence TE directly. Thirdly, we investigate the length of the positive impact of ICT on firm efficiency. Finally, we postulate that ICT effects on firm efficiency depend on certain complementary idiosyncratic factors (such as management practices, research and development investments and other firm' characteristics) that are able to boost ICT returns.

The analysis is conducted by means of a balanced and an unbalanced panel data of Italian manufacturing firms taken from four consecutive waves provided by Mediocredito-Capitalia-Unicredit (hereafter MCU) for the period 1995–2006.

The results provide evidence in favour of the above hypotheses by showing that ICT investments have a positive effect both on productivity and TE of Italian manufacturing firms, when ICT is considered as a general purpose factor and as a firm specific factor, and that firms benefit from ICT investments over a nine year period.

To explain the time-span in the impact of ICT on technical efficiency we postulate that investment in ICTs increases productivity according to firms' heterogeneous characteristics. The paper measures the duration of this impact, when accompanied by changes in management practices, complementary innovations and market competition. We demonstrate that firms that make changes in their organizational structure, that invest in research and development and that are open to international markets, exploit their ICT investments better, improving thereby efficiency.

The remainder of the work is structured as follows: the second section analyses the relevant literature at firm level. The third section presents the relationship between productivity and TE. The fourth

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section introduces the economic hypotheses and the stochastic frontier model. The fifth section describes the source of the data and the variables used. Results and discussion are presented in the sixth section together with robustness checks, while the final section offers concluding remarks.

2. Literature review

During the last few decades information and communication technologies have been at the centre of the debate on their contribution to economic growth and their long-lasting impact on productivity. This is a debate that, at the macroeconomic level, is still ongoing with different points of view and equivocal results (Baily et al., 2013; Brynjolfsson and McAfee, 2011; Byrne et al., 2013; Gordon, 2013), while, at the microeconomic level, the studies are going even deeper in measuring the diversified effects of ICT on firm performance and organization.

At the microeconomic level, the relationship between ICT investment, productivity and technical efficiency has been analysed for different countries and periods of time. The analysis is usually conducted with parametric and non-parametric methodologies that use a wide variety of estimation techniques: OLS, IV, logit, stochastic frontier, and data envelopment analysis. In order to verify the impact of ICTs on productivity and TE, this work utilizes the stochastic frontier model introduced by Battese and Coelli (1995). This methodology has the benefit of using a one-stage procedure to estimate both productivity and (in)efficiency.

Shao and Lin (2001, 2002), using both a stochastic and deterministic frontier production function on a panel data of United States firms, show that ICT has a significant positive effect on TE and hence contributes to productivity growth. Becchetti et al. (2003) evaluate the impact of investments in software, hardware and telecommunications of small and medium-sized Italian manufacturing firms on a series of intermediate variables and on productivity. In order to evaluate whether current ICT investments are able to affect firm efficiency, they use a Cobb–Douglas stochastic frontier approach. Their results show that investments in telecommunications positively affect the creation of new products and processes, while software investment increases the demand for skilled workers, average labour productivity and proximity to the optimal production frontier.

Mouelhi (2009), using a stochastic frontier approach on a panel data of Tunisian manufacturing firms, investigates whether the adoption of ICT impacts on the efficiency in factors use. The results show a positive return on ICT capital. Tunisian firms that make relatively intensive use of ICT are on average 5% more efficient than those that do not. Mouelhi's results also suggest that benefits from investment in ICT require complementary investments and changes in human capital.

Yuhn and Kwon (2010) investigate the link between IT and productivity growth in South Korea using the Brynjolfsson and Hitt's (2000) proposition that IT affects firm efficiency through new organizational and working practices. They follow Battese and Coelli (1992, 1995) in specifying the error term that measures technical efficiency. Using a panel data of Korean information technology-producing and using firms they find that 80% of the TFP firm's growth during the period 1990–2000 was due to technological change, 5% to scale economies and 15% to improvements in technical efficiency, mainly deriving from organizational and managerial changes required by IT investments.

Finally, Castiglione (2012), using both a Cobb–Douglas and a Translog production stochastic frontier, estimates the impact of ICT on TE in the Italian manufacturing firms over the period 1995–2003. The results show that ICT investments positively and significantly affected firm TE. Castiglione states that since the mean efficiency of the Italian manufacturing firms is 0.49 this implies that output could be in theory increased, and concludes that ICT investments and other factors might contribute to increasing productivity and technical efficiency.

To take a step further a distinction should be made between ICT and non-ICT capital and between high-skilled and low-skilled labour in stochastic frontier analysis. In this respect we make a research advance. In fact, while the relationship between ICT investments and firm productivity is a straightforward extension of the basic model of the production function that includes ICT and skilled labour as separate types of capital and labour, the inclusion of ICT investments as an additional input that affects firm efficiency is not a trivial problem.

In addition to the above aspects, some other factors should also be considered in this context. For example, Brynjolfsson and Hitt (1996) show that the impact of ICT investments on productivity varies from one firm to another, finding that some firms use ICTs in a more productive way than others. This could be ascribed to two different factors: idiosyncratic characteristics due to the rigidity of the cost structure and specific characteristics of organisational structure, such as strategy and management techniques. Dedrick et al. (2003) find that management experience and complementary investments explain part of the variation in ICT pay-offs. In a subsequent paper Brynjolfsson and Hitt (2003) demonstrate that computer investment generates output growth in the first year of installment, while output continues to grow over the years of service. They postulate that the increasing contribution of computers to productivity growth over the years (between 3 and 7 years) is mainly due to a broader set of assets that complement computers and make them work better over the computer's life-span. The present research is also an attempt to find those factors that explain the duration of this impact.

Atzeni and Carboni (2001), in explaining the importance of ICT adoption, apply a growth accounting methodology to calculate the total factor productivity residual over the period 1989–1997. This residual is then regressed on a number of variables including an estimate of ICT investments and their complements. Addressing the analysis to the question of territorial disparities, the authors find that the impact of ICT on productivity is significant and helps to explain the difference in firm performance between the North and South of Italy. Bugamelli and Pagano (2004) find strong evidence in favour of complementarity between ICT, human capital and reorganisation of production. Castiglione and Infante (2013), using data on Italian manufacturing firms, estimate a model on the TFP determinants that takes into account ICT investments and the key characteristics of a new ICT paradigm: pervasiveness, complementarity, and technological dynamism. They have found that firms that invest in ICT, even though they start from a lower TFP level, are able to reach higher efficiency levels, since their TFP increases faster than firms that do not invest in ICT.

Hall et al. (2013) in another recent work analyse the role of ICT and R&D investments on both innovation and productivity in an unbalanced panel of Italian manufacturing firms. They have investigated the interaction of the percentage of skilled workers with the two variables and found that skills significantly interact with R&D and produce a positive effect on a firm's innovative performance, while the interaction of skills with ICT do not. They conclude that the share of white-collar workers is complementary to R&D, but not to ICT as regards innovation.

Previous works have shown the importance of the complementary factors that ICT requires to have a greater effect on productivity. However, no attempt has been made to test the effects on TE of the ICT and its complementary factors. Very often the introduction of new managerial and work organization along with ICTs is done to boost productivity, without taking into account its effects on technical efficiency, thus underestimating the contribution of ICT to overall performance.

3. Productivity and technical efficiency

The firm production frontier specifies the maximum output achievable by employing a combination of inputs. The distance between the production frontier and actual output is regarded as its technical inefficiency. Thus, a firm operates below the frontier when it is technically inefficient and at the production frontier when it is technically efficient (Farrell, 1957). In production theory, productivity and TE are two related concepts, even though they represent two different performance measures. In fact, a firm may be technically efficient and may still be