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Abstract

This paper analyses the relationship between investment in Information and Communication Technologies (ICTs) and Technical Efficiency (TE). It uses a panel dataset of Italian manufacturing firms during the period 1995-2003. In contrast to much of the existing literature which focuses on the impact of ICT on labour or multifactor productivity, the paper analyses the relationship between ICT and TE using a stochastic frontier approach. Results show that ICT investment is positively associated with productivity and efficiency, but that the elasticities are lower than those associated with non-ICT capital and labour. Moreover, ICT investments have a positive effect on firm TE, and the impact of ICTs reduces firm inefficiency with a strong time lag since their adoption. Finally, the paper makes a methodological contribution by showing that a Cobb-Douglas production frontier is rejected in favour of a translog one.

Keywords: ICT, Stochastic Frontier, Technical Efficiency, Manufacturing Firms

JEL: D24, L25, L60, O33

1. Introduction

New investments in process and product innovation are important for existing and new firms. In fact, investment in information and communication technology (ICT) is considered important to a firm's economic performance.

The related empirical literature studies both the relationship between ICT investments and labour productivity and ICT investments and multifactor productivity (MFP). However, few attempts have been made to study the relationship between ICT investments and technical efficiency (TE) at firm level. The importance of this relationship arises from the fact the productivity growth is mainly the result of technical and efficiency changes. Hence, it is important to verify the effect that ICTs have both on productivity and TE.

In this paper the Cobb-Douglas and translog production functions are used to explore ICT investments impact on firm distance from the ''best practice technique'' by using a stochastic frontier approach. ICTs are considered as a factor able to influence TE, both as an input in the production function and as a variable able to explain inefficiency.

This work focuses on the period 1995-2003 using balanced and unbalanced panel data of Italian manufacturing firms taken from three surveys provided by Mediocredito Centrale-Capitalia.

The main contribution of this paper is that it demonstrates, at microeconomic level, that ICT investments show their benefit after some time. Moreover, to estimate the effect of ICT on TE, after constructing ICT capital stock we use a translog production function. Our results show that ICT investments have a positive effect on the TE of Italian manufacturing firms when ICT is considered both as a common factor and as a firm specific factor, and that firms need time to harness and to fully exploit ICTs.

The remainder of the work is structured as follows: the second section presents the basic framework of the relationship between TE and productivity. The third section analyses the relevant literature at firm level. The fourth one studies the economic model and the empirical approach used to evaluate the relationship between ICT and the distance from "efficient frontier". The fifth section describes the source of the data and the variables used. Results and discussion are presented in the sixty section, while some conclusions are drawn in the final section.

2. Basic framework

The firm production frontier specifies the maximum output achievable by employing a combination of inputs. The distance between the production frontier and the actual output is regarded as its technical inefficiency. Thus, a firm operates below the frontier when it is technically inefficient and on the production frontier when it is technically efficient (Farrell, 1957).

In production theory, TE and productivity are two related concepts, but they also represent two different performance measures. In fact, a firm may be technically efficient and may still be able to improve its productivity by exploiting scale economies, and by introducing new technologies (for a detailed analysis see Coelli et al., 1998). Therefore, an important relationship exists between productivity and TE. Leaving aside scale economies, productivity growth is the effect of the change in TE and the shift in the production frontier; thus, TE is one important factor in a firm's productivity, the other being technological change (Chen and McGinnis, 2007).

TE is concerned with the maximization of output for a given set of resource inputs and indicates how far the firm can increase its output without requiring further resources. A technically inefficient firm could produce the same output with less of at least one input or could use the same inputs to produce more of at least one output.

One way to represent TE is illustrated in *figure 1* in which labour and capital have been considered as the only inputs in the production process. Given two inputs and one output, the efficient frontier, or the "best practice" production function, may be represented by the isoquant that shows the minimum combination of inputs, given the state of the technology that can produce a given level of output. Technical change may be represented either by an upward shift in the production frontier or by a downward shift of the isoquant.

In *figure 1*, technical change is represented by investments in ICT; the first isoquant y_{nict} regards those firms which do not invest in ICT, whilst the second involves firms investing in ICT. With the new, lower isoquant, all firms, for each level of output, may use fewer inputs. A firm, using the two inputs labour and capital, to produce the output level y, is technically inefficient if it produces it at point *A* as compared to the frontier firm, which operates at point *B* if it does not invest in ICT and at point C if it does invest in ICT. Hence, the distance *AB* can be regarded as the firm's technical inefficiencies, while the distance *BC* can be regarded as technical progress. In fact, a firm operating at point *A* is inefficient because technically it could produce the same level of output using less input: moving to point *B* or, introducing ICTs, moving to point *C*. Hence firm inefficiency may be divided into two parts: technical inefficiency (from *A* to *B*) and the additional inefficiency due to the ICT *gap* (from *B* to C). Consequently, the inefficiency of a firm that does not invest in ICT depends on how far the firm is from its equilibrium point, that is, from a condition of fully utilizing its current technology, and on the adoption of the new technologies (Infante, 1990). In this work we also consider the additional efficiency that is present for firms that do invest in ICT.

3. Literature Review

At the microeconomic level, the relationship between productivity growth and improvement in efficiency from the use of the new technologies is greatly emphasised (Brynjolfsson and Hitt, 2000; Bugamelli and Pagano, 2004). Often, the microeconomic analysis is made with parametric methodologies that use different estimation methods: OLS, IV, logit, and stochastic frontier. Some of the main works on returns on ICT investments at microeconomic level are displayed in *table 1*. The table presents the recent literature in two parts. The upper part lists studies on returns of ICT investments on productivity regarding both labour productivity and multifactor productivity. The lower part presents studies on the effects of ICT investments on TE.

One of the major studies on ICT investment and productivity is the work of Brynjolfsson and Hitt (1996) which shows that the impact of ICT investments on productivity varies between firms. Some firms use ICTs in a more productive way compared to others. The cause could be ascribed to two different factors: firstly, idiosyncratic characteristics due to the rigidity of the cost structure; secondly, specific characteristics of organisational structure, such as strategy and management techniques, could be very important in the use of ICT. In fact, Dedrick et al. (2003) affirm that management experience and complementary investments explain part of the variation in ICT pay-offs.

Arvanitis (2004) finds that labour productivity in Swiss firms is closely correlated with ICT use, but also to human capital intensity and organisational factors such as team-work, job rotation and decentralization of decision making. This study also found evidence of complementarities between human capital and ICT capital with respect to productivity. However, Arvanitis did not find evidence of complementarities between organisational capital, human capital and ICT capital.

For Italy, Atzeni and Carboni (2001) use the data provided by Mediocredito Centrale-Capitalia over the period 1989-1997, and apply a growth accounting methodology to calculate the total factor productivity residual. This residual is then regressed on a number of variables including an estimate of ICT investments and their complements (for example, human capital). Addressing the analysis to territorial disparities, Atzeni and Carboni 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) combine two sources of firm-level data (Centrale dei Bilanci and Mediocredito Centrale–Capitalia) and estimate a short-run demand function for ICT capital based on production functions. They find strong evidence in favour of complementarity between ICT, human capital and reorganisation of production.

In a very recent paper, Hall et al. (2012), investigating on the role of R&D and ICT in the innovation process, using an unbalanced panel data from four Mediocredito Centrale-Capitalia surveys, find that both types of investments are strongly associated with innovation and productivity, with R&D being more important for innovation and ICT being more important for productivity.

Gilchrist et al. (2001), utilizing the same database as Brynjolfsson and Hitt (1996), estimate a Cobb-Douglas production function using a GMM technique and focus on manufacturing investments. They show that ICTs have a strong and parallel impact both on the growth of labour and multifactor productivity in durable goods sector.

The relationship between ICT investment and technical efficiency has been analysed by Shao and Lin (2001). The authors use a stochastic frontier production function on firm level panel data in the United States and show that ICT has a significant positive effect on TE and hence contributes to productivity growth. The following work of Shao and Lin (2002) is also carried out in two stages. The first stage involves the use of data envelopment analysis (DEA) to construct a nonparametric production frontier and measure the scores of TE. In the second stage, the efficiency scores are treated as a dependent variable and regressed upon the corresponding ICT investments to test whether ICT investment has a positive influence on TE. Their results confirm that an ICT investment exerts a positive impact on TE.

For developing countries, Assefa and Matambalya (2002) use cross-sectional data from a survey of SMEs in Tanzania, conducted by the Enterprise Research Group from 1999 to 2000. Their results show that efficiency gains could come from improvements in managerial skill and education of the labour force and from investment in ICTs.

Becchetti et al. (2003) analyze the determinants of ICT investment and the impact of the ICT component on labour productivity and efficiency on a sample of small and medium-sized firms, using the survey provided by Mediocredito Centrale-Capitalia over the period 1995-1997. They evaluate the impact of investments in software, hardware and telecommunications of these firms on a series of intermediate variables and on productivity. Subsequently, they use a Cobb-Douglas stochastic frontier approach in order to evaluate whether current ICT investments are able to affect firm efficiency. 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.

Gholami et al. (2004) using data from the Iranian manufacturing sector over the period 1993-1999 estimate the technical efficiency at industry level using panel data. The authors, following Shao and Lin (2001), estimate the impact of ICT on the productivity in two stages. In the first, they estimate a production function (both Cobb-Douglas and translog) and extract the productivity series from the residuals. In the second stage, the authors run a separate regression to estimate the impact of ICT investment on productivity. Their results confirm a positive and significant impact of ICT investments on productivity.

Mouelhi (2009) uses a panel data for the manufacturing sectors in Tunisia in order to investigate whether the adoption of ICT impacts on the efficiency in factors use. His results show a positive return on ICT capital. Firms that have a relatively intensive use of ICT are on average 5% more efficient that those that do not. Mouelhi's results also suggest that benefits from investment in ICT require complementary investments and changes in human capital. In fact, the combined use of ICT and human capital in a firm would enhance efficiency beyond the direct effects of these factors taken alone.

Recently, Castiglione (2012) using a panel data of Italian manufacturing firms, shows that ICT investments positively and significantly affect firms technical efficiency. In fact, the coefficient of ICT investments is found significantly negative, which indicates that when ICT investments increase, Italian manufacturing firms tend to have lower values of inefficiency effect, that is higher efficiency.

4. Economic Hypotheses and Empirical Approach

The purpose of this work is to find out whether ICT investments significantly affect the distance from the optimal production frontier. The impact of ICT investments on efficiency at firm level will be estimated by using the stochastic frontier approach for panel data. In this case the inefficiency effects (Battese and Coelli, 1995) are expressed as an explicit function of a vector of firm-specific variables and a random error. This approach has been recognised (Wang and Schmidt, 2002) to be better than the two-stage estimation which inconsistently assumes the independence of the inefficiency effects. The two-stage estimation procedure is unlikely to provide estimates which are as efficient as those that could be obtained using a single-stage estimation procedure.

In the past twenty years the demand for skilled workers has increased. According to Arvanitis (2004) many factors have contributed to this increase; however, most authors think that this effect is attributable primarily to skill-based technical change. The increase in demand for labour has led many authors to relate skill-biased technical change to the largest and most widespread new technologies of the past years (Bresnahan et al*.,* 2002). In this way, ICT and human capital build a “complementary system” of activities (Bresnahan et al*.,* 2002; Milgrom and Roberts, 1990). Given this strong complementarity between ICT and human capital, we also take into account the higher level of education of a firm’s employed workers, as a proxy of ICT labour. In our case, the ICT labour is approximated by the number of employees with university education and high secondary school education, while for the non-ICT labour the number of employees with compulsory education was used (see also Atzeni and Carboni, 2001; Becchetti et al., 2003).

ICT capital and ICT labour can be considered as separate production factors by themselves in measuring productivity and TE, in order to investigate ICT’s marginal products. Henceforth, our empirical analysis is focused on testing the following hypotheses:

Hypothesis 1: ICT capital and ICT labour represent major factors in the firm production function.
Hypothesis 2: ICT investments have a positive effect on TE in the production process.
Hypothesis 3: ICT investments influence TE within a lagged period of time.

In order to test the first hypothesis the stochastic frontier production function (Cobb-Douglas and translog) is used. Following Assefa and Matambalya (2002), Becchetti et al. (2003) and Castiglione (2012) raw materials are considered as input in the production function. Then the Cobb-Douglas production model takes the following form:

$$Y_{it} = \alpha Kict_{it}^{\beta_1} Knict_{it}^{\beta_2} Lict_{it}^{\beta_3} Lnict_{it}^{\beta_4} RM_{it}^{\beta_5} e^{v_{it}-u_{it}}$$

After taking the natural logarithm and adding a set of dummy variables the above equation becomes:

$$\ln(Y_{it}) = \beta_0 + \beta_1 \ln Kict_{it} + \beta_2 \ln Knict_{it} + \beta_3 \ln Lict_{it} + \beta_4 \ln Lnict_{it} + \beta_5 \ln RM_{it} + \\ + \sum_{\varphi} \alpha_{\varphi} Pav_{\varphi it} + \sum_{\eta} \alpha_{\eta} D_{\eta t} + v_{it} - u_{it} \quad (1)$$

where Y_{it} is the real output of the i^{th} firm at time t (*i=1,2,…,N* and *t=1,2,…T*); *Kict* and *Knict* are, respectively, the ICT and non ICT capital, *Lict* and *Lnict* are, respectively, the ICT and non ICT labour, *RM* the raw materials and *Pav* and *D* are, respectively, the dummy variables for

Pavitt sectors[1] and time period[2] t, v_{it} and u_{it} are, respectively, random errors and inefficiency effects.

The Cobb-Douglas satisfies the basic requirements for production frontiers, such as quasi-concavity and monotonicity; nevertheless, it imposes some restrictions, i.e. constant returns to scale and unitary elasticity of substitution, on production technology. A way to avoid such restrictions is to use the translog production frontier. However, since, according to Coelli et al. (1998), the Cobb-Douglas stochastic production frontier is a special case of the translog one, we decide to test the Cobb-Douglas against the translog functional form. The translog stochastic production frontier is specified as the following:

$$\ln(Y_{it}) = \beta_0 + \sum_{\gamma} \beta_{\gamma} \ln X_{\gamma it} + \frac{1}{2} \sum_{\gamma} \beta_{\gamma} (\ln X_{\gamma it})^2 + \sum_{\gamma \neq h} \sum_{h} \beta_{\gamma h} \ln X_{\gamma it} \ln X_{hit} + \\ + \sum_{\varphi} \alpha_{\varphi} Pav_{\varphi it} + \sum_{\eta} \alpha_{\eta} D_{\eta t} + v_{it} - u_{it} \quad (2)$$

where β denote parameter estimaters of the production function, *X* indicates the variables, γ and *h* denote inputs (i.e. logarithms of ICT capital (*Kict*), non-ICT capital (*Knict*), ICT labour (*Lict*) and non-ICT labour (*Lnict*) and raw materials (*RM*)) and t the year.

In order to test the second and third hypothesis, a second set of independent variables are required and are assumed to affect the (in)efficiency at which manufacturing firms convert factors of production into output. Thus, the inefficiency equation, in both cases (Cobb-Douglas and translog production frontier) is:

$$u_{it} = \alpha_0 + \delta_1 ICT_{it} + \delta_2 ICT_{it-1} + \delta_3 ICT_{it-2} + \delta_4 age_{it} + \delta_5 group_{it} + \sum_{j} \alpha_j size_{jit} + \\ + \sum_{s} \alpha_s * Area_{is} + \sum_{\varphi} \alpha_{\varphi} Pav_{\varphi it} + \sum_{\eta} \alpha_{\eta} D_{\eta t} + \varepsilon_{it} \quad (3)$$

where ICT investments are assumed able to negatively influence technical inefficiency. In equation (3) ICT represents the investments in information and communication technology at time t, t-1 (previous period) and t-2 (two period before), age indicates the age of the firms, group indicate if a firm is affiliated to corporate firms, size is the size of the firm: small if the

[1] In the Pavitt taxonomy the sectors are classified in the following way: supplier dominated (Pavitt 1), scale intensive (avitt 2), specialised supplier (Pavitt 3), and science based (Pavitt 4). This taxonomy finds its roots in the sources of the innovation, in the needs of users and in the appropriability capacity present in each sectors. Even if it is very broad this taxonomy permits, nevertheless, to see the ways through which a firm, a region build their technological basis. In fact, each sector of region may adopt and use ICT in a different, idiosyncratic way (Ciarli and Rabellotti, 2007).

[2] The three periods are: 1995-1997, 1998-2000, 2001-2003.

firm has 11-50 employees, medium if the firm has 51-250 employees; large if the firm has more than 250 employees, and Area, Pav, and D indicate, respectively, the dummy variables for the Italian macro territorial area, Pavitt sectors and time.

5. Data and descriptive statistics

The data used in this analysis are from the VII(1995–1997), VIII (1998–2000) and IX (2001–2003) surveys on Italian manufacturing firms carried out by Mediocredito Centrale–Capitalia. Nevertheless, we believe that the 1998-2003 years are the most important period for the introduction and use of ICTs.

The Mediocredito–Capitalia survey has been published every three years since 1968. The survey provides a great deal of information about production and financial indicators of Italian manufacturing firms. In the IX survey (2001–2003), the database considers a stratified sample of 3,452 firms, according to industry, geographical and dimensional distribution for firms from 11 to 500 employees. The survey is conducted by census for firms with more than 500 employees. The database contains information from questionnaires regarding the individual firm’s structure and behaviour, three years of balance sheet data, additional data on employees, such as their education, age of the firm, sales revenue, etc. Information related to ICT expenditure has only been present since 1995, it is given on a three-year basis (1995–1997, 1998–2000 and 2001–2003) and total annual investments are provided.

To merge the three different databases the variable “fiscal code” was used. The result is a sample of 4,497 firms in the seventh survey, of 4,680 firms in the eighth survey and 3,452 firms present in the ninth survey. The number of firms that are present in all the three samples are 514.

The definitions of the variables used are summarised in *table 3*. *Table 4* reports some descriptive statistics of the main variables for the unbalanced panel of 12,629 firms (observations). Following Becchetti et al. (2003) that use the seventh survey of the same database, both production function models are estimated with the variables expressed as three years averages. This choice is due to two database constraints, since the ICT investment variable is presented as a three year total amount; secondly and the employees’ education level is present just for the middle year.

The dependent variable in our estimations is the firms’ sales revenue, the proxy used for the labour is the number of employees and the proxy for the capital is the sum of fixed assets and immaterial assets. To choose these variables as proxies of output, capital and labour is quite common in the works that use the same survey (see: Infante, 1990; Gambardella and Torrisi, 2001; Becchetti et al., 2003; Bugamelli and Pagano, 2004).

The proxy for the ICT labour is the number of employees either with university education or with secondary high school education. For the non-ICT labour the number of employees with primary education was used[3] (Atzeni and Carboni, 2001; Becchetti et al., 2003). The assumption for these proxies is that labour that use non ICT technologies requires less education and more on the job training.

As said before, the Mediocredito-Capitalia survey reports the total ICT investments of the firm in the three years period covered by each survey used. Since the survey provides the total ICT investments for 3 years, to obtain ICT stocks two different methods are used in order to check if the results are influenced by the method applied.

The first is the perpetual inventory method (other works apply a similar methodology: e.g. Giuri et al., 2008). In this case, the value of non-ICT capital stock of the firm is constructed as fixed assets plus immaterial assets minus ICT capital and net assets due to annual amortisation. The sales revenue was deflated by the implicit price production deflator (year 2000=100) and capital, raw materials and the ICT investments are deflated by implicit investment deflator (year 2000=100).

In order to construct the ICT capital stock, it was assumed that the ICT investments are distributed in a similar way as total investments. For example, if the total investment for a firm is €30 million in 2001, €30 million in 2002 and €40 million in 2003, it is then assumed that the ICT investments are distributed in the same way, i.e., 30% is attributed to 2001, another 30% to 2002 and the final 40% to 2003. Then the perpetual inventory method was applied. This is a method that produces an estimate of the stock of fixed assets by estimating how many of the fixed assets installed as a result of gross fixed capital formation undertaken in previous years have survived to the current period.

The ICT capital stock is obtained in the following way:

$$K_t = I_t + (1-\delta)K_{t-1}$$

where δ is the investment depreciation rate and K_{t-1} is the capital stock at the end of the previous period. Following Oliner and Sichel (2000), it is assumed that δ is equal to 25%[4]. In this way the ICT capital stock over nine years can be constructed. The first task undertaken was to divide the investment over nine years, next the value from 1995-97 was converted in euro and

[3] The missing values, dropped from the analysis are 68 for the ICT labour and 1 for the non-ICT labour.
[4] Parisi et al. (2002) assume that the depreciation rate is equal to 15% but the estimated results are no different from the estimate with a depreciation rate equal to 25%.

deflated. It was then assumed that the ICT capital in 1994 is equal to zero, consequently the ICT capital stock in 1995 is equal to the value of investment in the same period.

In the second capital estimation method restrictions due to the data are taken into account to calculate the ICT capital stock. When the model is estimated with the unbalanced panel data it is assumed that the ICT and non-ICT capital is distributed in the firms as the average of the investments in three years. In other words, if the total investment is composed of 30% in ICT investments and 70% in non-ICT investments, the fixed assets are divided in the same way 30% as proxy of capital-ICT and 70% as proxy of non-ICT capital.

6. Results and Discussion

The parameters of the stochastic frontier production function are estimated by using the asymptotically efficient maximum likelihood method by FRONTIER 4.1[5].

The results of the impact of ICT investments on productivity and TE, specified in *equations 1-3,* are presented in *table 5*. The first column of *table 5* displays the results for the estimation of the Cobb-Douglas production frontier, while following columns refer to the translog results. The translog production frontier is estimated as an unbalanced panel of 12,629 firms (observations) present in the three surveys and as a balanced panel data of 1028 observations distributed over two periods 1998-2000 and 2001-2003, since the perpetual inventory method with 25% rate of depreciation was used to calculate the ICT capital stock. Moreover, since in the translog cross section estimation we introduce ICT investment lagged variables either for the previous period or two periods before, the sample is reduced to 514 observations. The different estimations are done in order to compare the results and to check for sample selection problems. The sign and the significance of variables are similar in the Cobb-Douglas and Translog stochastic frontier estimations.

The test of the first hypothesis is presented in the upper part of *table 5*. The test of the second hypothesis is presented in the lower part of the table, while the third one is presented in the last column of this table.

To test if the Cobb-Douglas production function is an adequate representation of the data, given the specification of the translog model, the likelihood ratio test was used. The purpose is to test the null hypothesis that the second order coefficients of the translog frontier are

[5] The FRONTIER 4.1 package uses the three steps estimation method procedure. These three steps provide a maximum likelihood estimate of the parameters of the stochastic frontier production function. The first step is an Ordinary Least Squares estimate of the function. Here all the estimators β, with the exception of the intercept β_0, are unbiased. At the second step a grid search on γ is conducted. The value for the parameters β (excepting β_0) are set to the OLS value, β_0 and σ^2 parameter are adjusted and all other parameters (μ,η and δ) are set to zero. At the last step the values in the grid search are used as starting values in an iterative procedure to obtain the maximum likelihood estimates.

simultaneously zero. The value of the generalised likelihood-ratio statistics for testing the null hypothesis for the panel frontier is computed in the following way:

$$LR = 2(-19256.468 + 20038.2) = 1563.464.$$

Thus the null hypothesis that the Cobb-Douglas frontier is an adequate representation of the data is rejected, given the specification of the translog stochastic frontier. Then, using a likelihood ratio test, the translog functional form is found to be a more appropriate fit for the data. The joint significance of the inefficiency variables is confirmed by using, again, a likelihood ratio test (not reported in the table).

To test the first hypothesis, i.e. ICT capital and labour as production factor in measuring TE, we need to use the factor elasticity. However, while the individual coefficients for the Cobb-Douglas model are elasticities and thus can be directly interpreted, in the case of the translog model, the elasticities are functions of the parameters and the level of the explanatory variables, and thus the individual coefficients cannot be directly interpreted as elasticities. Hence, for the case of the translog model the elasticities are calculated by partial derivatives.

Elasticities and returns to scale for the translog panel production frontier are displayed in *table 6.* The calculated elasticities are all positive, demonstrating that ICT capital and labour contribute positively to increasing the output as well as the other production factors. However, the returns to scale are equal to 0.85 in the balanced panel and 0.81 in the unbalanced panel, which implies that decreasing returns to scale are present in the Italian manufacturing sector over the period 1995-2003. The results of this analysis are similar in sign and significance to other analyses in the ICT literature (Assefa and Matambalya, 2002; Becchetti et al*.,* 2003; Gholami et al., 2004; and Shao and Lin, 2001, 2002).

However, the elasticities of ICT inputs (capital and labour) are still less than the elasticities of the non-ICT (capital and labour). For example, in the case of balanced panel data (*table 6*), the elasticities of ICT capital and labour are 0.03 and 0.09 respectively, while the elasticities of non-ICT capital and labour are 0.20 and 0.29. These results are similar to others in related papers. Bugamelli and Pagano (2004) found an elasticity of ICT capital equal to 0.04 and of other capital equal to 0.24. Shao and Lin (2001) found an elasticity of ICT investment equal to 0.05 and an elasticity of capital equal to 0.23. These differences in ICT and non-ICT inputs elasticity confirm the hypothesis that ICTs have not yet fully influenced firms that still heavily rely on non-ICT labour and capital.

The results of the test for the second hypothesis are reported in the second part of *table 5*. The coefficient estimates for ICT investments, in both specifications (Cobb-Douglas and translog balanced panel), is always significantly negative at 1 percent level, which indicates that higher ICT investment reduces firm inefficiency. This finding is consistent with the previous literature (Shao and Lin, 2002; Gholami et al., 2004).

Other control variables give the expected results. Older firms are significantly more efficient than the average. This also supports other findings (see Assefa and Matambalya, 2002) that firms become more efficient over time as a result of a growing stock of experience in the production process. Firms located in the North (north-east and north-west) and in the Centre and firms affiliated to corporate firms are significantly more efficient than Southern and non-corporate firms. This is consistent with the results of Atzeni and Carboni (2001) and Becchetti et al. (2003). In other words, firms situated in the North or Centre of Italy, which are more industrialised areas, are, on average, more efficient than firms situated in the South of Italy. Small and medium size firms and firms operating in the first three Pavitt sectors are significantly more efficient than large ones and firms operating in the fourth Pavitt sector. This may be attributed to the specific characteristics of the Italian manufacturing sector. In fact, almost all firms are of small-medium size and tend to be concentrated in the first Pavitt sector.

Column three in *table 5* presents the estimation for the unbalanced panel data (second method) as explained at the beginning of this section. The results for the unbalanced panel data do not significantly differ from the balanced one. All the explicative variables for the inefficiency are of the same sign and significance. This means that estimating balanced panel data does not generate sample selection problems.

The last column of *table 5* shows evidence for our third hypothesis, i.e. ICT investment influence TE with a lagged period of time. The estimation refers to a cross-sectional model using just the final period data (2001-2003) and includes in the efficiency equation the lagged value of ICT investments. The sign and the significance of parameters between the models, panel frontiers and stochastic frontier are similar. The parameter of ICT investments is not significant when it is lagged for one period. Conversely, it is negatively significant when it is lagged for two periods. This probably means that the ICT investments can increase the TE in a firm with a lagged period of between four and six years. This last result agrees with other works (Brynjolfsson and Hitt, 2000; David, 1990) which assert that ICT investments need a period of between three to ten years to show their full benefits.

7. Conclusions

In this work the impact of ICTs on firm technical efficiency is analysed. We contribute to the current literature demonstrating that ICT investments show their benefits after some time. Moreover, compared to the existing empirical literature on the role of ICT investments at firm level, this work provides two additional methodological contributions. The first deals with the functional form to be used in modelling the impact of ICT on technical efficiency, whereas the second concerns the use of a production function with the two inputs (capital and labour) divided in ICT and non-ICT to estimate the impact of ICT on productivity and technical efficiency in the Italian manufacturing sector.

As far as the functional form is concerned, both the Cobb-Douglas and the more flexible translog production function frontier were tested. The literature which this work refers on ICT investments generally omits testing the suitability of the Cobb Douglas specification. The results support our choice, since the Cobb Douglas production function was rejected in all models.

We have found positive results for all three hypotheses. Firstly, results indicate that ICT capital and labour have a positive and significant effect on productivity and technical efficiency in the production process of the Italian manufacturing firms. The econometric analysis confirms that substantial investments in ICT increase a firm's productivity even though these technologies have not yet overtaken the returns of traditional capital and labour. In fact, the elasticities of ICT capital and labour are still less than the elasticity of the non-ICT capital and labour. This probably means that the Italian firms were in a phase of transition regarding the new technological paradigm. According to same recent evidence (Hall at al., 2012), that use the same our source of data on a wider period, the contribution of ICT (and R&D) investments have large impacts on productivity, although Italian firms still underinvest in this activity.

Secondly, the key result of this analysis is that, in all estimations, the coefficient of ICT investments in the model for the inefficiency effects is significantly negative, which indicates that if ICT investments increase, firms tend to have a smaller value of inefficiency. Since the mean efficiency is found to be less than 0.60 a higher value of ICT investments can help the Italian manufacturing firms to increase their technical efficiency.

Finally, we have found that the impact of ICTs reduces firm inefficiency with a strong time lag since their adoption, demonstrating that firms need time to get used to these technologies before realising their full benefits. Probably, this time lag in efficiency gain was one of the factors in the 1990s debate on the Solovian productivity paradox. Researchers expected faster effects of ICT investment than those effectively reported in the short run productivity statistics.

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Figure 1: ICT Investments and Technical Efficiency

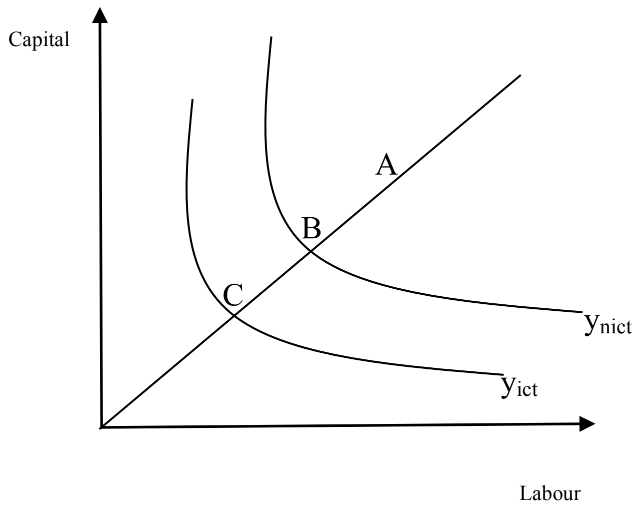

Table 1 - Some studies on returns of ICT investments at microeconomic level

Author(s), year	Method(s)	Results	Country	Period	Data
Arvanitis, 2004	MVCS*	Evidence for complementarities between ICT and human capital. No complementarity is found with organisation.	Tanzania	1999-00	Enterprise Research Group
Atzeni & Carboni, 2001	GA†-OLS	The impact of ICT on productivity is significant and helps explain the dualism in economic growth between the North and South of Italy.	Italy	1989-97	Mediocredito – Capitalia
Brynjolfsson & Hitt, 1996	OLS	Computers contribute significantly to firm-level output.	USA	1987-91	Computerworld
Bugamelli & Pagano, 2004	OLS-Probit	The results show strong evidence of complementarity between ICT, human capital and reorganisation of production.	Italy	1995-97	Centrale dei Bilanci Mediocredito - Capitalia
Gilchrist et al., 2001	..	IT productivity is greater in IT producer firms than in user firms and in durable manufacturing.	USA	1986-93	Panel of Fortune 1000 Manufacturing Firms
Hall et al. (2012)	Probit-OLS	R&D and ICT investments are both associated with firms innovation and productivity.	Italy	1995-06	Mediocredito-Capitalia
Assefa & Matambalya, 2002	SF	Investments in ICT positively influence efficiency gains.	Switzer.	2000	Survey of Swiss business sector
Becchetti et al., 2003	SF	Investment in telecommunications positively affects the creation of new products and processes, while software investment increases the demand for skilled workers, the average labour productivity and the proximity to optimal production frontier.	Italy	1995-97	Mediocredito – Capitalia
Castiglione, (2012)	Panel SF	ICT investments positively and significantly affected firms' technical efficiency in Italian manufacturing industry.	Italy	1995-03	Mediocredito - Capitalia
Gholami et al., 2004	Panel SF	Results confirm the positive and significant impact of ICT investment on productivity.	Iran	1993-99	Iranian National Bureau of Statistics
Mouelhi, 2009	SF	Results confirm the presence of positive returns to ICT capital. Moreover, the evidence shows that benefit from investment in ICT requires complementary investment and change in human capital.	Tunisia	1998-2002	National Annual Survey Report on Firms
Shao & Lin, 2001	Panel SF	The estimation of stochastic production frontiers to a firm-level panel data set highlight that IT has a significantly positive effect on technical efficiency.	USA	1988-92	Computerworld
Shao & Lin, 2002	DEA-Tobit	Statistical evidence confirms that IT investments exert a positive impact on technical efficiency.	USA	1988-92	Computerworld

Multivariate Cross-Section.
† Growth Accounting

Table 2 - Firms in the Mediocredito-Capitalia database

	Three year period 1995-1997	Three year period 1998-2000	Three year period 2001-2003	All periods
Observations	4497	4680	3452	514
Firms that invested in ICT	2984	3480	2111	491
Firms that invested but did not show the amount	128	156	253	..
Firms that did not invest in ICT	975	851	591	22
Firms that did not answer the question about ICT inv.	410	193	497	..

Table 3 - Variables used in the analysis

Variables	*Description*
Sales revenue	Sales revenue
K	Capital (fixed assets + immaterial assets)
Kict	ICT capital
Knict	Non-ICT capital: (fixed assets + immaterial assets - Kict)
Lict	ICT Labour: number of employees with university education and high secondary school education
Lnict	Non-ICT labour: number of employees with primary education.
ICT	Three year period ICT investments
Age	Firm's age
Group	Two dummy variables if the firm is affiliated to group
Size	Three dummy variables for firm size'. Small if the firm has 10–50 employees; medium if the firm has 51–250 employees; large if the firm has more than 250 employees
Area	Four dummy variables for the Italian macro areas
Pavitt	Four dummy variables for the sectors of activity of the firm, identified according to the Pavitt classification
D_year	Three dummy variables for time period

Table 4 - Descriptive statistics of Italian manufacturing firms (1995-2003)

Variables	Obs	Mean	Std. Dev.	Min	Max
Sales revenue	11368	4171564	65432.89	6.199	9786996
Capital	11368	4346.428	23030.19	11.424	1441835
Labour	11358	90.14319	269.930	7.333	10233
Raw materials	11002	1061.371	4261.189	0	225110.8
ICT Investments	11368	11289.42	9820.46	0	6460542

Table 5: Panel frontier production function with ICT investments as a production factor (t-statistics in parenthesis)

Variables/Parameter	*Cobb-Douglas*	Translog		
	Balanced PD	Balanced PD	Unbalanced PD	Cross-section
Constant	5.201	5.015	8-697	14.284
ICT capital	0.068 (0.370)	-0.200 (3.160) ***	0.092 (4.617) ***	-0.037 (3.342) ***
Non-ICT capital	0.350(13.23) ***	1.057 (9.024) ***	-0.263 (17.17) ***	-0.280 (8.813) ***
ICT labour	0.141 (3.971) ***	-0.119 (-8.678) ***	0.099 (11.91) ***	0.059 (2.563) ***
Non-ICT labour	0.326 (8.443) ***	-0.773 (4.287) ***	-0.010 (-1.351)	0.446 (1.299)
Raw materials	0.081 (6.642) ***	0.110 (1.768) *	-0.072 (-5.758) *	0.004 (4.043) ***
ICT capital Sq.		0.014 (1.357)	0.038 (7.571) ***	0.015 (0.957)
Non ICT capital sq,		0.220 (10.073) ***	0.124 (27.13) ***	0.124 (1.889) *
ICT labour Sq.		0.038 (0.677)	0.013 (1.568)	0.005 (0.043)
Non-ICT labour Sq.		0.256 (5.604) ***	0.003 (0.393)	0.016 (1.253)
Raw Mat. Sq.		0.076 (5.773) ***	0.095 (30.19) ***	0.048 (2.672) ***
ICT capital x non-ICT capital		0.059 (5.059) ***	-0.020 (-5.705) ***	-0.011 (-0.401)
ICT capital x ICT labour		0.013 (0.724)	0.001 (0.261)	-0.001 (0.430)
ICT capital x non-ICT labour		-0.077 (4.207) ***	0.004 (0.980)	-0.005 (-0.123)
ICT capital x Raw materials		0.003 (0.301)	-0.010 (-3.499) ***	0.015 (1.253)
Non-ICT capital x ICT labour		0.099 (4.469) ***	-0.005 (1.345)	0.053 (1.022)
Non-ICT capital x non ICT labour		0.121 (5.201) ***	0.003 (0.953)	-0.079 (1.524)
Non-ICT capital x raw materials		-0.009 (-0.740)	-0.024 (-13.55) ***	-0.022 (-9.686) ***
ICT labour x non-ICT labour		-0.138 (3.671) ***	-0.184 (3.121) ***	-0.080 (1.081)
ICT labour x raw Materials		-0.015(-0.815)	-0.002 (-0.573)	-0.005 (0.178)
Non-ICT labour x raw Materials		-0.065 (-2.864) ***	-0.005 (-1.785) *	-0.005 (-0.135)
D_pavitt_1	-0.089 (-0.485)	0.038 (0.196)	-0.543 (-9.840) ***	0.305 (1.186)
D_pavitt_3	0.096 (0.496)	0.227 (1.131)	-0.542 (-9.340) ***	0.594 (2.143)***
D_pavitt_4	-0.042 (-0.225)	0.089 (0.451)	-0.536 (-9.412) ***	0.309 (1.198)
D_2003-2001	7.072 (151.64) ***	7.152 (127.8) ***	7.272 (298.2) ***	
D_2000-1998			0.106 (4.396) ***	
Technical Efficiency variables				
ICT Investment	-0.767 (-12.34) ***	-0.437 (-6.729) ***	-1.633 (-33.025) ***	-0.434 (-5.250) ***
ICT Investment (previous period)				0.160 (0.652)
ICT Investment (two period before)				-2.474 (-7.893) ***
Age	-0.036 (-7.362) ***	-0.042 (-3.468) ***	-0.036 (-9.960) ***	-0.086 (-3.591) ***
D_group	-0.083 (-10.71) ***	-2.651 (-4.063) ***	-2.393 (-10.284) ***	-2.824 (-2.524) ***
D_small	-2.434 (-4.026) ***	-2.942 (-3.35) ***	-6.906 (-13.22) ***	-4.308 (-1.592)
D_medium	-3.523(-4.470) ***	-7.021(-6.494) ***	-10.528(-25.35) ***	-10.59 (-5.058) ***
D_area_1	-6.702 (-8.157) ***	-8.278 (-10.13) ***	-13.603 (-32.18) ***	-5.042(-1.950) *
D_area_2	-9.617 (-10.89) ***	-10.393 (-10.25) ***	-14.291 (-34.34) ***	-11.353 (-4.012) ***
D_area_3	-15.77 (-14.64) ***	-11.019 (-9.66) ***	-15.284 (-35.09) ***	-11.190 (-2.753) ***
D_pavitt_1	-17.61 (-17.19) ***	-13.76 (-10.01) ***	-18.53 (-28.29) ***	-7.817 (-5.180) ***
D_pavitt_2	-16.05 (-11.19) ***	-3.583 (-2.902) ***	-17.57 (-27.65) ***	6.712 (4.466) ***
D_pavitt_3	-0.789 (-0.680)	-11.753 (6.841) ***	-16.891 (25.11) ***	-5.262 (-4.010) ***
D_2003-2001	12.91 (8.528) ***	9.744 (11.13) ***	16.05 5(36.92) ***	
D_2000-1998			19.818 (63.394) ***	
Sigma-squared	33.938 (15.422) ***	20.508 (11.918) ***	44.656 (38.774) ***	34.176 (10.121) ***
Mean Efficiency	0.551	0.583	0.474	0.537
Nr. of obs	1028	1028	12629	514
Likelihood Ratio Tests				
Log Likelihood	-1423.7667	-1288.7730		
Test Statistics		269.9874		
Degree of Freedom		15		
Critical Value		24.99579		
Results		Reject CD		

Table 6: Descriptive statistics of the elasticities and returns to scale in the estimation of the ICT as a production factor (Translog model)

Variables	Balanced Panel Data		Unbalanced Panel Data	
	Mean	Std. Dev.	Mean	Std. Dev.
ICT Capital	0.027	0.063	0.046	0.074
Non-ICT Capital	0.204	0.207	0.309	0.169
ICT Labour	0.085	0.099	0.091	0.012
Non ICT Labour	0.292	0.281	0.180	0.054
Raw materials	0.240	0.084	0.193	0.228
Returns to Scale	0.847	0.190	0.819	0.305