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## Technical Efficiency and ICT Investment in Italian Manufacturing Firms

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*ICT Investment and Firm Technical Efficiency*

*Technical Efficiency and ICT Investment in Italian Manufacturing*  
*firms*

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**Abstract:** The importance of information and communication technologies (ICTs) is a much debated question with extensive literature aimed at understanding the role of ICTs in increasing economic growth, firm productivity and firm efficiency. Different methods to estimate firm efficiency are used in this study. In particular, both the translog and the Cobb-Douglas production functions are used in order to estimate the impact of information and communication technology on technical efficiency (TE) in Italian manufacturing firms over the period 1995-2003. Results show that ICT investments positively and significantly affected firms' technical efficiency. Moreover, group, size and geographical position have a positive influence on TE. Finally, the results show that older firms are, on average, more efficient than newer ones.

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## I. Introduction

The influence of information and communication technology (ICT) is a topic that has received increased attention from economists over the past two decades, its impact on economic growth being the subject of numerous studies at both aggregate and firm levels (Brynjolfsson and Hitt, 1996; Gordon, 2000; Oliner and Sichel, 2000).

During the 1980s and early 1990s many researchers asserted that the contribution of ICT to productivity and economic growth was either very small or non-existent (Gilchrist *et al.*, 2001). These findings are often associated with the Solow paradox, which states that: “You can see the computer age everywhere but in the productivity statistics”. Nevertheless, the latest studies increasingly assert the importance of new technologies.

The empirical literature focuses on the relationship between ICT investments and labour productivity or ICT investments and Total Factor Productivity (TFP). Some attempts have been made to study the relationship between ICT investments and technical efficiency (TE) at firm level (Assefa and Matambalya, 2002; Becchetti *et al.*, 2003; Gholami *et al.*, 2004 and Shao and Lin, 2001; 2002).

This work starts by over-viewing the previous literature and moves in two directions. Firstly, two different production functions, Cobb-Douglas and Translog, are used to explore investments and the average distance of producers from the “best practice” by using a stochastic frontier approach. Both production functions are used since the Cobb-Douglas requires the elasticity of substitution between factors to be unity while the translog production function is a generalization of the Cobb-Douglas which relaxes this restriction. Secondly, ICT

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4 technologies are considered as a factor which is able to influence technical  
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6 efficiency.  
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9 In this work, the impact of ICT technologies on technical efficiency is analysed  
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11 under the hypothesis that a greater use of ICT at firm and economy level may help  
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13 firms to increase their efficiency. The purpose of this work is to investigate  
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15 whether ICT investments significantly affect a firm's distance from the optimal  
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17 production frontier. In order to test this hypothesis, the stochastic frontier  
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19 production function is adopted utilising an unbalanced panel data of Italian  
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21 manufacturing firms elaborated from the results of the VII, VIII and IX surveys  
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23 carried out by Mediocredito Centrale-Capitalia (MCC). ~~Other works use the same~~  
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25 ~~surveys (VII or VIII) to study the relationship between ICT investments and~~  
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27 ~~productivity growth (Atzeni and Carboni, 2001; Bugamelli and Pagano, 2004),~~  
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29 ~~total factor productivity growth (Gambardella and Torrasi, 2001) or technical~~  
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31 ~~efficiency (Becchetti et al., 2003).~~  
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38 ~~Our results show that ICT investments have a positive effect on the technical~~  
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40 ~~efficiency of Italian manufacturing firms when ICT is considered to be a firm~~  
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42 ~~specific factor.~~  
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45 The remainder of this paper is structured as follows: the first section focuses on  
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47 the productivity paradox from a historical context and on the ICT contribution to  
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49 economic growth. The second section presents the methodology, which  
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51 encompasses the economic model and the empirical approach in order to evaluate  
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53 the relationship between ICT and distance from the "efficient frontier", and  
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55 describes the data used. To conclude, results and comments are presented.  
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## II. Theoretical background

Robert Solow's (1987) assertion that “You can see the computer age everywhere but in the productivity statistics” is still the object of much investigation, although the latest studies increasingly assert the importance of new technologies. In fact, recent productivity and GDP growth has been mainly related to the impact of information and communication technology investments.

Many economists describe this controversy as “the productivity paradox”. The idea of this paradox emerged in the late 1980s when it was questioned whether ICT delivered its promised returns in increasing productivity. However, this paradox no longer seemed to be relevant after Brynjolfsson and Hitt (1996) presented their significant firm-level empirical evidence suggesting that the paradox had become a thing of the past by the beginning of the 1990s.

Today, the importance of new technologies can be observed in many studies, both in theoretical and applied economics. In fact, over the past twenty years the impact of ICT on economic growth has been the subject of numerous studies at different levels: i.e. firms, industries and countries (Jorgenson, 2001; Oliner and Sichel, 2000).

Gordon (2000, 2002), who expressed different conclusions in the past, now affirms that ICT investments contribute more than other technologies to economic growth. Moreover, more than ten years after the statement of the paradox, Solow himself admitted that the statistics were beginning to measure the influence of the computer age, albeit still modestly at the moment<sup>1</sup>. There is now persuasive evidence that the boom in information and communication technology

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<sup>1</sup> Solow is quoted as such in Gordon (2002)

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4 investments of the 1990s has led to significant changes in the absolute and relative  
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6 productivity performance of firms, sectors and countries. For example, at the  
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8 microeconomic level, Brynjolfsson and Hitt (2000) and Gilchrist *et al.* (2001)  
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10 show that the payoffs to ICT investments occur not just in labour productivity but  
11  
12 also in total factor productivity.  
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### 20 *ICT contribution to economic growth*

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22 Empirical analysis of economic growth and productivity typically distinguishes  
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24 three effects of ICT (Kenneth *et al.*, 1994; Pilat, 2004). First, the “production  
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26 effect”: the firms producing these technologies can help economic growth at an  
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28 aggregate level, either through a rapid increase in demand for these products  
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30 compared with other sectors or through a higher level of productivity in the same  
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32 sector. In fact, technological progress in the production of ICT goods directly  
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34 raises total factor productivity in ICT-producing industries.  
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39 The second is the “using effect”: firms in traditional sectors increase capital  
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41 stock per worker (capital deepening) in order to acquire new technologies, this  
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43 implies an increase in output per worker. Engelbrecht and Xayavong (2005) assert  
44  
45 that the fall in ICT capital prices with respect to those of other types of capital  
46  
47 encourages firms to substitute the former for the latter. In this way, an increase in  
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49 investment in ICT capital contributes to labour productivity growth in ICT using  
50  
51 industries through capital deepening effects. Schreyer (2000) points out that  
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53 substitution processes are an important element in assessing the role of ICT in  
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55 production. This approach treats ICT capital goods like all other types of capital  
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57 goods. In particular, it is assumed that firms which own ICT assets are able to  
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4 reaped most or all of the benefits that accrue from using new technologies.  
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6 Moreover, a greater use of ICT throughout the economy may help firms to  
7  
8 increase their overall efficiency.  
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11 Furthermore, greater use of ICT may contribute to network effects, such as  
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13 lower transaction costs and more rapid innovation, which should also improve  
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15 TFP. In fact, the third effect of ICT is “total factor productivity”: the adopting of  
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17 new technology improves the performance of all the factors used. Consequently,  
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19 output increases without further input investment. An increase in total factor  
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21 productivity means that, at a given input level and a fixed quality, an economy  
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23 always obtains higher output levels (Castiglione, 2008).  
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29 Finally, many other authors suggest that ICT generates a fourth effect in the  
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31 form of spillovers through efficiency gains in the production process, and through  
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33 the accumulation of intangible organizational capital accompanying investment in  
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35 ICT capital (Stiroh, 2000; Basu et al., 2003). Such positive externalities, or  
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37 spillover effects, may accelerate TFP growth in ICT using industries.  
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41 In this work ICTs are considered as General Purpose Technologies (GPTs) i.e.  
42  
43 fundamental technological innovations that are characterised by pervasiveness,  
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45 technological dynamism and innovative complementarities. The technological  
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47 dynamism characteristic indicates continuous efforts at innovation, as well as  
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49 learning, increasing over time the efficiency with which the generic function is  
50  
51 performed (Bresnahan and Trajtenberg, 1995). This should show up as a reduction  
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53 in prices, an increase in quality, or both. The improvement a GPT brings about  
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55 can therefore be measured in terms of how much cheaper a unit of quality  
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57 becomes over time. If technology is embodied in capital, then presumably capital  
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4 as a whole should become cheaper and faster during a GPT period, especially  
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6 capital which is tied to the new technology.  
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9 During the GPT phase, technological progress could be separated into two  
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11 dimensions. One would be a new technological paradigm (i.e. steam engine or  
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13 electricity) and the other would be an increasing number of innovations within the  
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15 paradigm. With the two different types of technological progress the production  
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17 function is shifted up.  
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21 Helpman and Trajtenberg (1996) assert that each time a new GPT appears, it  
22  
23 generates a cycle consisting of two distinct phases. During the first phase  
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25 resources are diverted to the development of complementary inputs permitting  
26  
27 exploitation of the new GPT. Output and productivity experience negative growth  
28  
29 and the real wage stagnates. In the second phase, after enough complementary  
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31 inputs have been developed, old inputs are replaced by the more productive GPT.  
32  
33 During this phase output, real wages and profits increase.  
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38 In this way it is possible also to explain the productivity paradox. In fact, from  
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40 the study by Jovanovic and Rousseau (2005), it is possible to assert that the  
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42 slowing down of productivity during the ICT period could be explained as a  
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44 learning phase, but when investments in new technologies increase productivity  
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46 should rapidly increase (Castiglione, 2006).  
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### 53 **III. Stochastic frontier approach**

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55 We assume that ICT are GPT because, according to Bresnahan and Trajtenberg  
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57 (1995), they open the road to new opportunities for existing technologies too,  
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59 improving the performances of all the factors used. To verify this hypothesis the  
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4 contribution of ICT investment to firm productivity is explored empirically using  
5 a stochastic production frontier approach. The production frontier, which  
6 characterises the relationship between inputs and output, specifies the maximum  
7 output achievable by employing a combination of inputs. The distance between  
8 the production frontier and the actual output is regarded as the firm's technical  
9 inefficiency. Thus, a firm either operates below the frontier when it is technically  
10 inefficient or it operates on the production frontier when it is technically efficient.  
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21 The concept of TE was elaborated by Farrell (1957) who stated that the  
22 efficiency of a firm consists of two components: technical efficiency and  
23 allocative efficiency. TE is concerned with the maximisation of output for a given  
24 set of resource inputs and indicates the ability of a firm to obtain maximum output  
25 from a given set of inputs. Allocative efficiency reflects the firm's ability to use  
26 inputs in optimal proportions, given their respective price and the production  
27 technology. Jha et al. (1998) use Data Envelopment Analysis (DEA) in order to  
28 measure both technical and allocative efficiency in Indian firms. Together  
29 technical and allocative efficiency provide a measure of total economic efficiency.  
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42 According to Battese and Coelli (1995) productivity growth from one year to  
43 the next can be the result either of efficiency improvements or to technical  
44 change. *Fig. 1* shows a typical production frontier,  $SF$ , with one input  $x$  and one  
45 output  $y$ . Technical change may be represented by an upward shift in the  
46 production frontier. This is depicted in *Fig. 1* by the movement in the production  
47 frontier from  $SF_{NICT}$  to  $SF_{ICT}$ .  
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57 With the new, higher production frontier all firms may technically produce  
58 more output for each level of input, compared with what was possible with the  
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4 lower production frontier. In our work, technical change is represented by  
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6 investments in ICT; the first production frontier  $SF_{NICT}$  regards those firms which  
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8 do not invest in ICT whilst the second regards firms investing in ICT.  
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11 Suppose a firm operates at point  $A$ . According to the production frontier, the  
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13 firm might increase its output level to point  $B$  if it does not invest in ICT and to  
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15 point  $B'$  if it does invest in ICT, using the same input  $X_1$ , and, hence, the distance  
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17  $AB'$  can be regarded as the firm's technical inefficiency. In fact, a firm operating  
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19 at point  $A$  is inefficient because technically it could increase output to the level  
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21 associated with point  $B$  or  $B'$  with no extra input or, alternatively, it could  
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23 produce the same level of output using less input: producing at point  $D$  or  $D'$  on  
24  
25 the frontier.  
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31 [Insert Figure 1 about here]  
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34 Hence inefficiency may be divided into two parts: technical inefficiency (from  
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36  $A$  to  $B$ ) and the additional inefficiency due to the ICT gap (from  $B$  to  $B'$ ).  
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39 Another definition of TE is the ratio  $AB'/B'C$  representing technical  
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41 inefficiency and  $AC/B'C (=1-AB'/B'C)$  representing TE. On the other hand, in  
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43 terms of the inefficiency due to the ICT gap, we can write:  $AB/BC$  for technical  
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45 inefficiency and  $AC/BC (=1-AB/BC)$  to represent technical efficiency. "One  
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47 advantage of these ratio measures for technical efficiency is that they are unit  
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49 invariant; i.e. changing the units of measurements does not change the scores of  
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51 efficiency measurement. This ratio of technical efficiency will take on a value  
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53 between zero and one, with a higher score implying higher technical efficiency"  
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57 (Shao and Lin, 2001: 448). A technically inefficient firm could produce the same  
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4 output with at least one input fewer or could use the same input to produce at least  
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6 one output more.  
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9 The measurement of technical efficiency has widely been associated with the  
10 use of production frontier functions. As Arestis (2006) pointed out traditional  
11 econometric estimation techniques (such as ordinary least squares) fail to measure  
12 a production frontier, because they allow some of the observed output bundles  
13 produced by a given set of inputs to be greater than the estimated maximal  
14 producible output. Albert (1998) suggests to estimate an idealized production  
15 frontier (*best-practice frontier*) in which “efficient agents can be localized and the  
16 deviations of all other firms from this frontier (inefficiencies) can be calculated.”  
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18 (Albert, 1998: 723).  
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30 Several techniques to determine these frontier functions have been used:  
31 parametric and non-parametric. The choice of estimation method has been a  
32 subject of debate (Seiford, 1996) since every method has its advantages and  
33 disadvantages. The principal advantage of the estimation of a non-parametric  
34 production frontier, using for example the data envelopment analysis (DEA)  
35 technique, is that it does not require any assumptions regarding the functional  
36 form. Also DEA does not require an explicit assumption about the inefficiency  
37 term (Odeck, 2007; Shao and Lin, 2002). However, using this kind of technique, it  
38 is not possible to distinguish whether the lack of efficiency is due to technical  
39 inefficiency or to statistical noise (Odeck, 2007: 2618).  
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54 The parametric approach requires the assumption of a specific functional form  
55 (e.g. Cobb-Douglas, translog, constant elasticity of substitution - CES) for the  
56 technology (constant or variable returns to scale) and an explicit distributional  
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4 assumption for the inefficiency term. It uses econometric techniques to estimate  
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6 the coefficients of the production function as well as the technical efficiency. The  
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8 main strengths are that the parametric approach deals with stochastic noise and  
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10 also allows statistical tests of hypotheses concerning production structure and the  
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12 degree of inefficiency. The first step in parametric stochastic frontier estimation  
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14 is, then, to select an appropriate functional form for the production function.  
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19 A number of studies (Carroll *et al.*, 2007; Gholami *et al.*, 2004 and Shao and  
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21 Lin, 2001) have estimated both the Cobb-Douglas and the translog functional  
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23 form and some of them (Carroll *et al.*, 2007) have tested the null hypothesis that  
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25 the Cobb-Douglas form is an adequate representation of the data, given the  
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27 specification of the translog model.  
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#### 34 *Cobb-Douglas and translog production frontier*

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36 The Cobb-Douglas production frontier has been one of the most frequently used  
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38 functional specifications in research on production economics. It satisfies the  
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40 basic requirements for production frontiers, such as quasi-concavity and  
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42 monotonicity. It imposes properties upon the production structure such as fixed  
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44 returns to scale and an elasticity of substitution which is equal to unity.  
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49 The Cobb-Douglas stochastic production frontier with two inputs, capital ( $K$ )  
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51 and labour ( $L$ ), and one output ( $Y$ ) can be specified as:

$$52 \quad Y_i = \alpha K_i^{\beta_k} L_i^{\beta_L} e^{v_i - u_i}$$

53  
54 where  $i$  is the index which considers the number of firms. After taking the natural  
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56 logarithm, the production function can be rewritten in the following way:  
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$$\ln(Y_i) = \beta_0 + \beta_K \ln K_i + \beta_L \ln L_i + v_i - u_i$$

The random error  $v_i$  is assumed to be independent and identically distributed (i.i.d.) with zero mean and constant variance  $N(0, \sigma_v^2)$ .

On the other hand, the residual component  $u_i$  of technical inefficiency represents the effects of events incurred by the firm. These technical inefficiencies are assumed to be non-negative random variables of independently, but not identically distributed, truncated normal distributions. The underlying normal distribution is assumed to be  $N(\mu_i, \sigma_\mu^2)$ . TE is predicted using the conditional expectation of  $\exp(-U_i)$ , given the composed error term of the stochastic frontier.

Technical efficiency equals one only when a firm has an inefficiency effect equal to zero; otherwise it is less than one. If  $U_i$  is equal to zero, this means that there is no inefficiency in production, the firm is technically efficient and produces its maximum potential output. Conversely, when  $U_i$  has values lower than zero this implies that there is inefficiency in the firm's production and it produces less than its maximum possible output given the technology. The magnitude of  $U_i$  measures the "efficiency gap", that is how far a given firm's output is from its potential output. In order to compute TE it is, therefore, necessary to estimate across potential output which can be achieved by the econometric estimation of the stochastic frontier production function.

A number of alternative functional forms have also been used in production frontier literature. The most popular is the translog function.

The two input, translog, stochastic production frontier can be specified in the following way:

$$\ln(Y_i) = \beta_0 + \beta_K \ln K_i + \beta_L \ln L_i + \frac{1}{2} [\beta_{KK} (\ln K_i)^2 + \beta_{LL} (\ln L_i)^2] + \beta_{KL} \ln K_i \ln L_i + v_i - u_i$$

The assumptions about the random error  $v_i$  and the technical efficiency  $u_i$  remain the same as in the Cobb-Douglas stochastic production frontier.

The translog function does not impose the same restrictions upon the production structure as the Cobb-Douglas production function, but it may suffer from degrees of freedom and multicollinearity problems. However, the Cobb-Douglas stochastic production frontier is a special case of the translog stochastic production frontier under the following restrictions:

$$\beta_{KK} = \beta_{KL} = \beta_{LL} = 0$$

The translog function is non-homogeneous and belongs to the class of flexible functional forms, which provides a second-order local approximation to any functional form (Coelli *et al.*, 1998).

#### *Stochastic frontier for panel data*

Panel data models have some advantages over cross-sectional data in the estimation of stochastic frontier models. Schmidt and Sickles (1984) assert that the first advantage is that, while cross-section models assume that the inefficiency term and the input levels are independent, for panel data estimations this hypothesis is not needed. This is useful in order to introduce time-invariant regressors into the specification of the model. Moreover, by adding a temporal dimension to the observed unit data, panel data stochastic frontier models yield consistent estimates of the inefficiency term. Furthermore, by exploiting the link between the “one-sided inefficiency term” and the “firm effect” concepts,



Schmidt and Sickles (1984) observed that, when panel data are available, there is no need for any distribution assumption for the inefficiency effect and all the relevant parameters of the frontier technology can be obtained by simply using the traditional estimation procedures for panel data; i.e. fixed-effects model and random-effects model approaches. Finally, panel data permit the simultaneous investigation of both technical change and technical efficiency change over time.

The panel data stochastic frontier models can be written in the following way:

$$Y_{it} = \beta_0 + \sum_{n=1}^N \beta_n X_{nit} + v_{it} - u_{it}, \quad i = 1, 2, \dots, N; \quad t = 1, 2, \dots, T$$

where  $Y_{it}$  denotes the output for the  $i^{th}$  firm at the  $t^{th}$  time period,  $X_{it}$  denotes a (1xk) vector of inputs associated with the suitable functional form,  $\beta$  is a (kx1) vector, to be estimated, of unknown scalar parameters,  $u_{it}$  are the inefficiency effects in the model and  $v_{it}$  are random errors, assumed to be i.i.d. and have  $N(0, \sigma_v^2)$  distribution, independent of  $u_{it}$ .

Sometimes it is assumed that technical inefficiency effects are time invariant:

$$u_{it} = u_i \quad i = 1, 2, \dots, N; \quad t = 1, 2, \dots, T.$$

“The assumption that technical inefficiency effects are time-invariant is more difficult to justify as T becomes larger. One would expect that managers learn from their previous experience in the production process and so their technical inefficiency effects would change in some persistent pattern over time” (Battese and Coelli, 1995: 203).

The model proposed by Battese and Coelli (1995) specifies technical inefficiency effects in the stochastic frontier model that are assumed to be independently (but not identically) distributed non-negative random variables. For

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4 the  $i^{\text{th}}$  firm in the  $t^{\text{th}}$  period, the technical inefficiency effect,  $u_{it}$ , is obtained by a  
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7 truncation of the  $N(\mu_{it}, \sigma^2)$  distribution, where  $u_{it} = z_{it}\delta$ . In this case  $z_{it}$  is a  
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10 (1xM) vector of observable explanatory variables, whose values are fixed  
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12 constants; and  $\delta$  is a (Mx1) vector, to be estimated, of unknown scalar  
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14 parameters.

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17 The log-likelihood function of this model is described in Battese and Coelli  
18  
19 (1992) where  $\sigma_s^2 = \sigma_v^2 + \sigma^2$  and  $\gamma = \sigma^2 / \sigma_s^2$ , with  $\gamma$ -parameter values between zero  
20  
21 and one.  
22  
23

#### 24 25 26 **IV. Economic model and empirical approach**

27  
28 The main purpose of this work is to investigate whether ICT investments  
29  
30 significantly affect a firm's distance from the optimal production frontier. Using  
31  
32 the stochastic frontier approach, the inefficiency effects are expressed as an  
33  
34 explicit function of a vector of firm-specific variables and a random error. This  
35  
36 approach has been widely recognised to be better than the two-stage estimation  
37  
38 procedure which assumes independence of the inefficiency effects. The two-stage  
39  
40 estimation procedure is unlikely to provide estimates which are as efficient as  
41  
42 those that could be obtained using a single-stage estimation procedure (Becchetti  
43  
44 *et al.*, 2003).  
45  
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50 The empirical analysis is based on the following hypothesis: ICT investment  
51  
52 has a positive effect on technical efficiency in the production process. In order to  
53  
54 test this hypothesis the stochastic frontier production function (Cobb-Douglas and  
55  
56 translog) is used. To estimate firm efficiency, it is important to include all  
57  
58 possible inputs in the production function, because omission of one of the input  
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60

factors may give a relatively higher efficiency to a firm which is using a greater quantity of these inputs. If this happens, two firms which, *ceteris paribus*, produce the same output may be located at the same point (e.g.: point *B* in *fig. 1*) on the production frontier, while, in reality, the one that uses a greater quantity of the non included input, lies at a lower point (e.g.: point *A* in *fig. 1*), because it is less efficient (Infante, 1990).

Following Becchetti *et al.* (2003) and Assefa and Matambalya (2002), raw materials are considered along with labour and capital as inputs in the production function. So, the Cobb-Douglas production model takes the following form:

$$Y_{it} = \alpha K_{it}^{\beta_1} L_{it}^{\beta_2} RM_{it}^{\beta_3} e^{v_{it} - u_{it}}.$$

After taking the natural logarithm and adding a set of dummy variables (i.e. three for the four Pavitt sectors<sup>2</sup>, and two for the three time periods<sup>3</sup>) the equation becomes:

$$\ln(Y_{it}) = \beta_0 + \beta_1 \ln K_{it} + \beta_2 \ln L_{it} + \beta_3 \ln RM_{it} + \sum_{j=1}^{m-1} \alpha_j * Pav_{ijt} + \sum_{t=1}^T \alpha_t D_{it} + v_{it} - u_{it} \quad (1)$$

where  $Y_{it}$  is the real output of the  $i^{th}$  firm at time  $t$  ( $i=1,2,\dots,N$  and  $t=1,2,\dots,T$ );  $K$  is the capital,  $L$  the labour,  $RM$  the raw materials and  $Pav$  and  $D$  are, respectively, the dummy variables for Pavitt sector and time period.

As indicated, the Cobb-Douglas production frontier imposes some restrictions, such as fixed returns to scale and unitary elasticity of substitution, on production technology. Hence, it is tested against the translog functional form. The translog

<sup>2</sup> In the Pavitt taxonomy the sectors are classified in the following way: supplier dominated (Pavitt 1), scale intensive (Pavitt 2), specialised supplier (Pavitt 3) and science based (Pavitt 4).

<sup>3</sup> The three periods are: 1995-1997, 1998-2000 and 2001-2003.

stochastic production frontier with three inputs (capital, labour and raw materials) can be specified as:

$$\begin{aligned} \ln(Y_i) = & \beta_0 + \beta_1 \ln K_{it} + \beta_2 \ln L_{it} + \beta_3 \ln RM_{it} + \beta_4 \frac{(\ln K_{it})^2}{2} + \beta_5 \frac{(\ln L_{it})^2}{2} + \\ & + \beta_6 \frac{(\ln RM_{it})^2}{2} + \beta_7 \ln K_{it} \ln L_{it} + \beta_8 \ln K_{it} \ln RM_{it} + \beta_9 \ln L_{it} \ln RM_{it} + \\ & + \sum_{j=1}^{m-1} \alpha_j * Pav_{ijt} + \sum_{t=1}^T \alpha_t D_{it} + v_{it} - u_{it} \end{aligned} \quad (2)$$

To estimate the model a second set of independent variables is required and they are assumed to affect the level of efficiency at which manufacturing firms convert factors of production into output. The first variable is ICT investments since it is assumed that they are able to influence technical (in)efficiency. For the other variables, the theory does not point to any specific factor that should be included “it is more of an empirical question. As such, variables are selected on the basis of economic intuition” (Carroll *et al.*, 2007: 6).

In this work ICT investment, age, firms affiliated to corporate firm, size of firm, geographic macroarea, Pavitt sectors and time period are considered as explicative firm efficiency variables. So, the inefficiency equation, in both cases (Cobb-Douglas and translog production frontier), is:

$$\begin{aligned} u_{it} = & \alpha_0 + \delta_1 ICT_{it} + \delta_2 age_{it} + \delta_3 group_{it} + \sum_{j=1}^{m-1} \alpha_j * size_{ijt} + \sum_{s=1}^{n-1} \alpha_s * Area_{ist} + \sum_{\gamma=1}^{n-1} \alpha_\gamma * Pav_{i\gamma t} \\ & + \sum_{t=1}^{T-1} \alpha_t D_{it} + \varepsilon_{it} \end{aligned} \quad (3)$$

where *ICT* represents investments in information and communication technology, *group* indicates whether a firm is affiliated to a corporate firm, *size* is the size of the firm (small if the 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*

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4 indicate, respectively, the dummy variables for the Italian macro-territorial area,  
5  
6 Pavitt sectors and time.  
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8  
9 The empirical evidence of the impact of ICT on firm performance is mixed. In  
10  
11 fact, in developed countries, the growth of total factor productivity associated  
12  
13 with technical change has even declined with the increased use of ICT of the past  
14  
15 10 to 20 years (Jorgenson and Stiroh, 1999). It was only in the 1990s that  
16  
17 empirical evidence showed that ICT has a substantial effect on firm productivity  
18  
19 levels. Therefore, in this model, ICT investments have been included in order to  
20  
21 understand whether there is a positive relationship between technical efficiency  
22  
23 and ICT investments. Consequently, if the coefficient estimates for  $\delta_1$  is  
24  
25 significantly negative, there is empirical evidence to confirm that ICT has a  
26  
27 favourable effect on technical efficiency.  
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33 The expected signs for all estimated *beta* parameters in the Cobb-Douglas  
34  
35 production frontier and the elasticities in the translog production frontier are  
36  
37 positive since each factor contributes to production positively. For *delta*  
38  
39 parameters, the economic literature is used to hypothesise about the expected sign.  
40  
41

42 A positive relationship between *age* and technical efficiency can be expected  
43  
44 due to “learning by doing” which occurs through production experience. Over  
45  
46 time, firms become more efficient as a result of a growing stock of experience in  
47  
48 the production process. However, other economists argue that when an innovation  
49  
50 is introduced, newer firms generally adopt it easily, while older firms may have to  
51  
52 delay adoption as it may be too costly to substitute old methods, thus implying  
53  
54 that efficiency may decrease with age (Assefa and Matambalya, 2002). Empirical  
55  
56 studies also report mixed results regarding the relationship between a firm’s age  
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4 and technical efficiency. Assefa and Matambalya (2002) assert that some studies  
5 have found a positive relationship between firm age and efficiency, other studies  
6 have reported a negative relationship between firm efficiency and age; while,  
7 some other studies have indicated that the effect of age could be neutral (Cheng  
8 and Tang, 1987).

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16 The relationship between firms affiliated to corporate firms and TE should be  
17  
18 positive as indicated in the literature which affirms that groups have relatively  
19  
20 higher productivity and superior competitiveness with respect to individual firms  
21  
22 (Becchetti, 2003) (i.e. the expected sign is negative).  
23  
24

25  
26 The effect of firm *size* on efficiency is ambiguous since empirical evidence  
27  
28 does not suggest a strong link between efficiency and firm size in either direction.  
29  
30 “While a positive effect may be expected on the grounds of scale of economies,  
31  
32 firm size may be negatively linked to efficiency if large firms experience  
33  
34 management and supervision problems” (Assefa and Matambalya, 2002: 20). On  
35  
36 the other side, Jha et al. (1998) find that large firm size is associated with higher  
37  
38 technical as well as allocative efficiency.  
39  
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43 Finally, dummy variables for the Italian macro area are also included to control  
44  
45 for regional differences due to different level of development; Pavitt dummies are  
46  
47 included because an industrial sector may have, in principle, a different  
48  
49 production function from others; and temporal dummies are included to take into  
50  
51 account technological progress. The expected sign for firms located in the centre  
52  
53 or the north Italy is negative since those firms should be more efficient than firms  
54  
55 located in the south. For the time dummy, the expected sign for the parameter is  
56  
57 negative because, if there is technological progress, inefficiency should decrease.  
58  
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## V. Variables and descriptive statistics

For this analysis, the VII (1995-1997), VIII (1998-2000) and IX (2001-2003) surveys of manufacturing firms by the MCC were used. The database has been published every three years since 1968.

The survey provides a great deal of information about the production and financial indicators of Italian manufacturing firms. In the last survey, the database considers a stratified sample of 3,452 Italian manufacturing firms. The sample is stratified according to industry, geographical and dimensional distribution for firms from 11 to 500 employees. It is by census for firms with more than 500 employees.

The database contains questionnaire information regarding the individual firms' structure and behaviour, three years of balance sheet data, additional data on employees, employees' education, age of the firm, turnover, etc. Information relating to ICT expenditure has only been present since 1995, is displayed on a three-year level (1995-1997, 1998-2000 and 2001-2003) and total annual investment is provided. However, data on the stock of ICT capital are not provided. Also the variable for employees' education is displayed as one value for three years.

*Table 1* analyses the ICT variable in the last three surveys. For example, in the IX survey (2001-2003), of over 3,452 firms, 591 did not invest in ICT, 253 firms said that they had invested in ICT in those three years but did not reply to the question "How much money did you invest on average in the last three years?" and 497 firms did not answer either question.

[Insert Table 1 about here]

Following the method of Becchetti *et al.* (2003), who used the same data source (seventh survey), both models are estimated with the variables expressed as three year averages. Due to the fact that the ICT investment variable is expressed as a three year value. Turnover was deflated by an implicit price production deflator (2000=100) and capital, raw materials and ICT investments are deflated by an implicit investment deflator (2000=100).

The dependent variable is the firms' turnover, the proxy used for labour is the number of employees and the proxy for 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 previous works using the same survey (see for example: Becchetti *et al.*, 2003; Gambardella and Torrìsi, 2001; Bugamelli and Pagano, 2004).

## VI. Results and discussions

### *ICT investments and technical efficiency*

The parameters of the stochastic frontier production function are estimated using the asymptotically efficient maximum likelihood method by FRONTIER 4.1<sup>4</sup>.

The results regarding the impact of ICT investments on technical efficiency specified in equations 1-3 are presented in *table 2*. Both models (Cobb-Douglas

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<sup>4</sup> 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  $\beta$ , with the exception of the intercept  $\beta_0$ , will be unbiased. In the second step, a grid search on  $\gamma$  is conducted. The value for the parameters  $\beta$  (excepting  $\beta_0$ ) are set to the OLS value,  $\beta_0$  and  $\sigma^2$  parameters are adjusted and all other parameters ( $\mu, \eta$  and  $\delta$ ) are set to zero. In the final step, the values in the grid search are used as starting values in an iterative procedure to obtain the maximum likelihood estimates.



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4 and Translog) presented in the previous section are estimated as a cross-section of  
5  
6 the period 2001-2003 and as an unbalanced panel of 12,629 firms (observations)  
7  
8 present in the VII, VIII and IX surveys provided by the MCC. This is done in  
9  
10 order to compare the results and to check for sample selections issues. The sign  
11  
12 and the significance of the variables between the two models, panel frontier and  
13  
14 stochastic frontier, are not different.  
15  
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17

18 [Insert Table 2 about here]  
19

20  
21 To test whether the Cobb-Douglas production function is an adequate  
22  
23 representation of the data, given the specification of the translog model, the  
24  
25 likelihood ratio test was used. The purpose of this is to test the null hypothesis that  
26  
27 the second order coefficients of the translog frontier are simultaneously zero:  
28  
29  $H_0 = \beta_{ij} = 0$  for all  $i \leq j = 1,2,3$ .  
30  
31  
32

33 The value of the generalised likelihood-ratio statistics for testing null  
34  
35 hypothesis for the panel frontier in the case of the complete translog production  
36  
37 function is computed in the following way:  
38  
39

$$40 \quad LR = 2(-19256.468 + 20038.2) = 1563.464$$

41  
42 Thus the null hypothesis that the Cobb-Douglas frontier is an adequate  
43  
44 representation of the data is rejected, given the specification of the stochastic  
45  
46 frontier. In other words, using a likelihood ratio test, the translog functional form  
47  
48 is found to be a more appropriate fit for the data<sup>5</sup>.  
49  
50  
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52 All *beta* coefficients in the Cobb-Douglas production function are significantly  
53  
54 positive, confirming that each factor contributes positively to production. The  
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57  
58 <sup>5</sup> The likelihood ratio test is equal to:  $2*(Unrestricted-Restricted)$  and follows a chi-squared distribution.  
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4 joint significance of the inefficiency variables is confirmed by again using a  
5  
6 likelihood ratio test.  
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9 The coefficient estimates for the ICT investment is always significantly  
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11 negative with a 1% significance level, which indicates that more ICT investments  
12  
13 have a negative effect on inefficiency (i.e., a positive effect on efficiency).  
14  
15 Therefore, the null hypothesis is never rejected. This implies that ICT investments  
16  
17 have a positive effect on the technical efficiency of the Italian manufacturing  
18  
19 industry. This finding is consistent with the previous literature (Gholami *et al.*,  
20  
21 2004; Shao and Lin, 2002).  
22  
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26 Other control variables give the expected results. Firms located in the North  
27  
28 (east and west) and in the Centre and firms affiliated to corporate firms are  
29  
30 significantly more efficient than the average. This is consistent with the results of  
31  
32 Atzeni and Carboni (2001) and Becchetti *et al.* (2003). In other words, firms  
33  
34 situated in the north or centre of Italy, which are more industrialised areas, are, on  
35  
36 average, more efficient than firms situated in South of Italy.  
37  
38

39  
40 Despite Jha *et al.* (1998) results asserting that large firm in agriculture sector in  
41  
42 India are with higher technical and allocative efficiency, in this paper small and  
43  
44 medium size firms and firms operating in the first three Pavitt sectors are  
45  
46 significantly more efficient than the average. This may be attributed to the  
47  
48 specific characteristics of the Italian manufacturing sector. In fact, almost all firms  
49  
50 are of small-medium dimensions and tend to be concentrated in the first Pavitt  
51  
52 sector.  
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56 Results show, moreover, that older firms are significantly more efficient than  
57  
58 the average. This supports the theory (Assefa and Matambalya, 2002) that firms  
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4 All the elasticities are positive, however returns to scale are equal to 0.84,  
5 which implies that decreasing returns to scale were present in the Italian  
6 manufacturing sector over the period 1995-2003. This finding agrees with other  
7 works which show that, in the period considered, the Italian manufacturing sector  
8 presented decreasing returns to scale (Medda and Piga, 2004; Bonaccorsi and  
9 Granelli, 2005).

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*Table 4* displays mean efficiency by year. It is evident that efficiency declined  
in three year period 1998-2000 and increased in the next period. However, if the  
period 2001-2003 is compared with 1995-1997, average efficiency decreased.  
This result confirms the previous findings of decreasing returns to scale. In fact, if  
a firm has experienced a decrease in inefficiency, it may use the same input to  
produce more output or produce the same amount of output with less input.

[Insert Table 4 about here]

#### *Unbalanced panel and attrition*

With a balanced panel, the same units appear in each time period. Conversely,  
with an unbalanced panel some units do not appear in every time period. If the  
reason a firm leaves the sample (attrition) is correlated with the idiosyncratic  
error, then the resulting sample section problem may cause biased estimators  
(Wooldridge, 2002).

In other words, unbalanced panel data may arise for several reasons (i.e.  
rotating panel, incidental truncation). A “problem arises when attrition from a  
panel is due to units electing to drop out. If this decision is based on factors that  
are systematically related to the response variable, even after we condition on

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3  
4 explanatory variables, a sample selection problem can result” (Wooldridge, 2002:  
5  
6  
7 578).

8  
9 In order to check whether selection is an issue in this paper the balanced panel  
10 data is estimated and a selection indicator is added to the unbalanced panel data.  
11  
12 The results for the balanced panel data estimations are presented in *table 5*.  
13  
14

15  
16 [Insert Table 5 about here]  
17

18 The sign and the significance of variables are not different from the unbalanced  
19 panel data. The coefficient estimates for ICT investments is always significantly  
20 negative with a 1% significance level, which indicates that more ICT investments  
21 have a negative effect on inefficiency. Therefore, in this case too, the hypothesis  
22 that ICT investments are able to increase technical efficiency is not rejected. All  
23 the other variables are of the expected sign and the interpretation is the same as  
24 before. The Cobb-Douglas panel frontier is rejected in favour of the translog panel  
25 frontier.  
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38 *Table 6* presents the results for elasticities, returns to scale and efficiency by  
39 year for the translog complete model.  
40

41  
42 [Insert Table 6 about here]  
43

44 The results for the calculated elasticities and returns to scale are similar to the  
45 previous estimation. In fact, the elasticities are all positive and the returns to scale  
46 are equal to 0.81, which confirms the previous finding that decreasing returns to  
47 scale were present in the Italian manufacturing sector over the period 1995-2003.  
48  
49

50 The only difference with the unbalanced panel is that, in this case, the  
51 efficiency scores by year were also increasing over the 2 time periods 1995-1997  
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4 and 1998-2000. However, in this case too, mean efficiency is 0.51 which implies  
5  
6 that output could theoretically have increased.  
7

8  
9 The second step of the attrition analysis is to construct the selection indicator.  
10  
11 The selection indicator assumes a value of 0 for firms that are always present in  
12  
13 the panel and for attriters the selection indicator is equal to 1 in the period just  
14  
15 before attrition (Wooldridge, 2002).  
16  
17

18  
19 The selection indicator is included in the production function and in the  
20  
21 efficiency equation (and given separately to make sure identification is not an  
22  
23 issue). The results are displayed in *Table 7*. In this case the null hypothesis is that:  
24  
25  $u_{it}$  is uncorrelated with  $s_{it}$  for all periods, where  $s_{it}$  represents the selection  
26  
27 indicators. In no cases can the null hypothesis be rejected, so it is possible to  
28  
29 conclude that selection is not a problem in this sample.  
30  
31

32  
33 [Insert Table 7 about here]  
34  
35

## 36 37 38 **VII. Conclusion**

39  
40 The impact of ICT investments on firm performance was a highly debated topic  
41  
42 after Solow's assertion that "You can see the computer age everywhere but in the  
43  
44 productivity statistics". A lot of economists referred to this assertion as "the  
45  
46 productivity paradox".  
47  
48

49  
50 The productivity paradox seemed to be solved after Brynjolfsson and Hitt  
51  
52 (1996) presented their significant firm-level empirical evidence. In fact, recent  
53  
54 studies have been able to show the positive relation between ICT investments and  
55  
56 productivity, and consequently, end the controversy over the ICT productivity  
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4 paradox. Our results confirm that the paradox no longer stands for Italian  
5  
6 manufacturing firms either.  
7

8  
9 In this work, the impact of ICT technologies on technical efficiency is analysed  
10  
11 using an unbalanced panel of data (1995-2003) on Italian manufacturing firms.  
12  
13 The data utilised were the VII, VIII and IX surveys by the MCC.  
14

15  
16 Compared to the existing empirical literature on the role of ICT investments at  
17  
18 firm level, this work deals with the functional form to be used in modelling the  
19  
20 impact of ICT on technical efficiency. Not many studies have considered  
21  
22 economic performance measures like the technical efficiency of the production  
23  
24 process in the area of ICT. However, this methodology may be interpreted as  
25  
26 another way to explain the productivity paradox given the close relationship  
27  
28 between productivity and technical efficiency.  
29  
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31

32  
33 As far as functional form is concerned, both the Cobb-Douglas and the translog  
34  
35 production function frontier were used because the translog is more flexible than  
36  
37 the Cobb-Douglas. The results support this choice, since the assumption inherent  
38  
39 in the technology of a Cobb Douglas was rejected in all models. Moreover, the  
40  
41 literature on ICT investments to which this work refers generally omits testing of  
42  
43 the suitability of the Cobb-Douglas specification.  
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46  
47 Our results indicate that information and communication technology  
48  
49 investments have a positive and significant effect on technical efficiency in the  
50  
51 production process of Italian manufacturing firms. In fact, the coefficient of ICT  
52  
53 investments is significantly negative, which indicates that, if ICT investments  
54  
55 increase, Italian manufacturing firms tend to have lower values of inefficiency  
56  
57 effects i.e. higher efficiency.  
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4 Other control variables used in the inefficiency equation give expected results.  
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6 Firms located in the North and in the Centre and firms affiliated to corporate  
7  
8 groups are significantly more efficient than the average. Moreover older firms are  
9  
10 significantly more efficient than the average.  
11  
12

13  
14 Mean efficiency is 0.49 which implies that output could theoretically be  
15  
16 increased. This may be ascribed to the fact that ICT investments are still a small  
17  
18 proportion of total investments (22%). This partially confirms David's hypothesis  
19  
20 (1990), which states that new technologies have to reach a spread rate of 50% for  
21  
22 their positive effects to show.  
23  
24

25  
26 However, it should be noted that investments in technological capital are not  
27  
28 the only way to achieve higher growth; other factors might be the positive  
29  
30 externalities due to the ICT investment growth in some sectors, human capital  
31  
32 and/or structural changes in different sectors.  
33  
34

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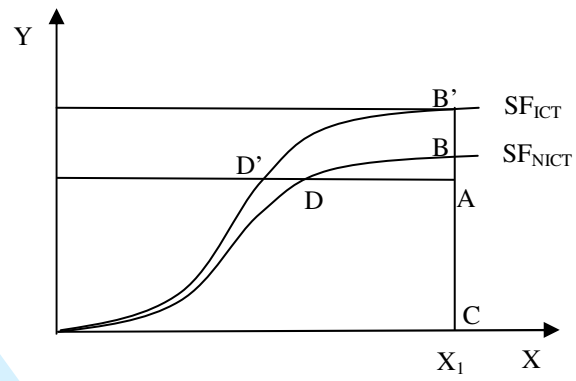
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For Peer Review

Fig. 1: The Production Frontier



For Peer Review

*Table 1 – Number of firms surveyed*

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

For Peer Review

Table 2 - Cobb-Douglas and translog production frontier with ICT investments as a specific factor of production (t-statistics in parenthesis)

Parameter	Cobb-Douglas				Translog			
	Cross-section Frontier		Panel Frontier		Cross-section Frontier		Panel Frontier	
Constant <sup>6</sup>	12.995	12.894	6.366	6.078	15.00	14.28	7.360	6.863
Capital	0.150 (10.11)***	0.165 (11.00)***	0.216 (3.709)***	0.157 (34.16)***	-0.351 (-4.822)***	-0.243 (-4.166)***	0.118 (6.142)***	0.064 (2.704)***
Labour	0.689 (28.68)***	0.683 (26.92)***	0.570 (53.90)***	0.705 (78.62)***	0.301 (2.691)***	0.440 (5.055)***	-0.110 (-2.217)**	0.048 (3.896)***
Raw materials <sup>7</sup>	0.052 (7.022)***	0.058 (7.307)***	0.058 (12.46)***	0.056 (15.40)***	0.175 (4.322)***	0.167 (4.382)***	0.152 (7.693)***	0.111 (5.688)***
Capital Sq.					0.110 (7.976)***	0.097 (9.556)***	0.029 (6.670)***	0.045 (8.669)***
Labour Sq.					0.252 (6.078)***	0.209 (6.592)***	0.218 (16.67)***	0.237 (12.32)***
Raw Mat. Sq.					0.060 (9.661)***	0.061 (8.163)***	0.077 (19.36)***	0.078 (22.79)***
Cap. x Lab.					-0.056 (-3.026)***	-0.053 (-3.701)***	-0.001 (-0.166)	-0.023 (-2.870)***
Cap. x Raw Mat.					-0.012 (-1.647)*	-0.013 (-1.722)*	-0.023 (-7.467)***	-0.018 (-5.419)***
Labour x Raw Mat.					-0.072 (-5.861)***	-0.069 (-5.937)***	-0.061 (-9.951)***	-0.061 (-10.39)***
D_pavitt_1	-0.070 (-0.085)	-0.181 (-2.332)**	-0.085 (-1.750)*	-0.491 (-10.33)***	-0.015 (-0.191)	-0.129 (-1.965)**	0.054 (0.964)	-0.184 (-4.771)***
D_pavitt_3	-0.016 (-0.017)	-0.103 (1.245)	-0.090 (-1.795)*	-0.492 (-0.984)	0.020 (0.235)***	-0.100 (-1.441)	0.042 (0.964)	-0.213 (-4.900)***
D_pavitt_4	-0.180 (-2.132)**	-0.288 (-3.714)***	-0.174 (-3.578)***	-0.581 (-12.020)***	-0.915 (-1.121)	-0.210 (-3.116)***	-0.025 (-0.580)	-0.252 (-5.777)***
D_2003-2001			6.493 (237.14)***	7.062 (359.16)***			6.594 (265.79)***	7.087 (300.7)***
D_1998-2000			-0.551 (-20.34)***	-0.082 (-3.743)***			-0.466 (-18.02)***	-0.037 (-1.722)*
Technical Efficiency variables								
Inv. ICT <sup>8</sup>	-0.221 (-19.320)***	-1.460 (-25.65)***	-1.388 (-18.827)***	-1.412 (-41.36)***	-2.427 (-18.95)***	-1.439 (-22.57)***	-1.570 (-28.11)***	-1.351 (-57.54)***
Age		-0.010 (-0.527)		-0.036 (-7.362)***		-0.020 (-2.420)**		-0.028 (-3.875)***
D_group		-5.800 (-9.220)***		-3.331 (-11.40)***		-2.879 (-3.520)***		-1.641 (-5.823)***
D_small		-0.114 (-0.207)		-10.568 (-22.66)***		1.693 (1.503)		-14.17 (-15.46)***
D_medium		-2.402 (-4.083)***		-10.118 (-20.95)***		3.493 (4.719)***		-14.613 (-27.36)***
D_area_1		-26.91 (-23.08)***		-14.20 (-28.80)***		-26.77 (-21.19)***		-14.96 (-15.13)***
D_area_2		-29.43 (-34.37)***		-15.14 (-34.39)***		-29.25 (-28.15)***		-15.68 (-17.91)***
D_area_3		-29.24 (-32.47)***		-16.00 (-35.80)***		-29.20 (-26.93)***		-16.80 (-14.32)***
D_pavitt_1		-9.498 (-9.145)***		-18.45 (-26.24)***		-9.934 (-6.554)***		-14.48 (-38.14)***
D_pavitt_2		-8.509 (-6.876)***		-17.37 (-24.01)***		-9.658 (-7.407)***		-13.38 (-32.90)***
D_pavitt_3		-9.823 (-10.25)***		-17.36 (-22.91)***		-10.04 (-23.29)***		-13.40 (-36.36)***
D_2003-2001				15.50 (49.60)***				15.50 (36.03)***
D_1998-2000				20.34 (59.22)***				21.73 (103.2)***
Sigma-squared	26.188 (27.607)***	65.053 (28.610)***	13.093 (54.479)***	45.615 (35.037)***	26.468 (26.28)***	61.404 (23.29)***	13.744 (50.857)***	43.193 (22.434)***
Gamma	0.991 (27.607)***	0.997 (4570.96)***	0.979 (1317.4)***	0.994 (3958.19)***	0.993 (2072.2)***	0.997 (4764.34)***	0.985 (1824.64)***	0.996 (3159.73)***
Mean Efficiency	0.455	0.488	0.403	0.489	0.473	0.503	0.420	0.502
Nr of obs	3452	3452	12629	12629	3452	3452	12629	12629
Likelihood Ratio Tests								
Log Likelihood	-6339.7297	-5527.2709	-22854.614	-20038.2	-6197.740	-5385.362	-22374.204	-19256.468
Test Statistics					283.980	283.817	960.82	1563.464
Degree of Freedom					6	6	6	6
Critical Value					12.592	18.307	12.592	28.869
Results					Reject CD	Reject CD	Reject CD	Reject CD

<sup>6</sup> \*\*\* indicates significance of 1%, \*\* at 5% and \* at 10%.

<sup>7</sup> Before taking the logs, 1 was summed to raw materials since there were some firms with 0 values for these variables.

<sup>8</sup> Since there were some firms that did not invest in ICT before taking the logs 1 was summed to the investment in ICT.



Table 3 - Descriptive statistics of elasticities and returns to scale (translog complete model)

Variable	Obs	Mean	Std. Dev.
Capital	11553	0.212	0.054
Labour	11553	0.487	0.192
Raw materials	11553	0.139	0.176
Returns to Scale	11553	0.838	0.171

Table 4 - Descriptive Statistics of Efficiency Scores by Year (Translog complete model)

Variable	Obs	Mean	Std. Dev.
1995-1997	11553	0.561	0.178
1998-2000	11553	0.438	0.235
2001-2003	11553	0.511	0.197

Table 5 - Cobb-Douglas and translog production frontiers with ICT investments as a specific factor of production (t-statistics in parenthesis)

Parameter	Balanced Panel Frontier			
	Cobb-Douglas Panel Frontier		Translog Panel Frontier	
Constant <sup>9</sup>	6.027	5.579	7.588	7.360
Capital	0.169 (10.03)***	0.132 (8.75)***	0.021 (3.248)***	-0.344 (5.303)***
Labour	0.656 (23.07)***	0.736 (28.91)***	0.021 (1.603)	0.047 (3.492)***
Raw materials <sup>10</sup>	0.058 (5.45)***	0.059 (6.12)***	-0.007 (1.115)	0.039 (6.674)***
Capital Sq.			0.031 (1.96)**	0.040 (2.456)***
Labour Sq.			0.100 (3.39)***	0.147 (3.609)***
Raw Mat. Sq.			0.058 (6.10)***	0.060 (6.512)***
Cap. x Lab.			0.006 (3.135)***	-0.001 (-0.920)
Cap. x Raw Mat.			-0.016 (-1.588)***	-0.013 (-1.400)
Lab. X Raw Mat.			-0.008 (-4.321)***	-0.026 (-1.350)
D_pavitt_1	-0.107 (-0.629)	-0.233 (-1.76)*	0.133 (0.964)	-0.131 (-1.080)
D_pavitt_3	-0.088 (-0.508)	-0.053 (-0.383)	0.136 (0.996)	-0.054 (-4.254)***
D_pavitt_4	-0.170 (-1.003)	-0.236 (-1.723)*	0.097 (0.715)	-0.102 (-0.805)
D_2003-2001	6.557 (114.60)***	7.072 (137.98)***	6.581 (125.81)***	6.955 (141.7)***
D_1998-2000	-0.239 (-9.36)***	-0.022 (-3.743)***	-0.226 (-4.218)***	-0.011 (-2.211)**
	Technical Efficiency variables			
Inv. ICT <sup>11</sup>	-1.139 (-9.358)***	-1.019 (-13.99) ***	-1.321 (-10.06)***	-0.671 (-10.61)***
Age		-0.065 (-7.507)***		-0.068 (-10.063)***
D_group		0.862 (0.138)		-1.350 (-2.498)**
D_small		-1.292 (-2.00)**		-6.136 (-7.139)***
D_medium		-2.215(-3.51)***		-10.784(-11.727)***
D_area_1		-4.53 (-6.07)***		-7.013 (-10.217)***
D_area_2		-8.47 (-10.22)***		-12.381 (-14.40)***
D_area_3		-9.98 (-14.02)***		-13.99 (-14.42)***
D_pavitt_1		-8.24 (-5.93)***		-12.41 (-9.18)***
D_pavitt_2		-1.198 (0.92)		-5.00 (-3.290)***
D_pavitt_3		-7.21 (-5.26)***		-10.03 (-6.153)***
D_2003-2001		16.26 (28.97)***		-7.79 (-12.46)***
D_1998-2000		9.28 (-10.77)***		9.28 (-10.77)***
Sigma-squared	8.289 (16.597) ***	25.943 (11.379)***	8.547 (16.855)***	26.330 (22.434)***
Gamma	0.973 (367.2) ***	0.992 (1099.90)***	0.978 (446.69)***	0.994 (1580.65)***
Mean Efficiency	0.485	0.574	0.503	0.580
Nr of obs	1542	1542	1542	1542
	Likelihood Ratio Tests			
Log Likelihood	-22854.614	-20038.2	-2341.86	-1939.39
Test Statistics			57.33	107.78
Degree of Freed.			6	6
Critical Value			12.592	28.869
Results			Reject CD	Reject CD

<sup>9</sup>\*\*\* indicates significance of 1%, \*\* at 5% and \* at 10%.

<sup>10</sup> Before taking the logs I was summed to raw materials since there were some firms with 0 values for these variables.

<sup>11</sup> Since there were some firms that did not invest in ICT before taking the logs I was summed to the investment in ICT.

Table 6 - Descriptive statistics of elasticities, returns to scale and efficiency scores by year  
(translog complete model – balanced panel data)

Elasticities and returns to scale			Efficiency scores by year		
Variable	Mean	Std. Dev.	Year	Mean	Std. Dev.
Capital	0.183	0.053			
Labour	0.484	0.116	1995-1997	0.446	0.166
Raw materials	0.140	0.135	1998-2000	0.509	0.148
Returns to Scale	0.806	0.201	2001-2003	0.586	0.162

Table 7 - Translog production frontier with selection indicator (t-statistics in parenthesis)

Parameter	Translog		
	Production Frontier	Unbalanced Panel Frontier	Production Frontier And Efficiency Equations
Constant <sup>12</sup>	6.989	6.992	6.992
Capital	0.060 (3.082)***	0.060 (3.246)***	0.118 (6.142)***
Labour	0.011 (2.326)**	0.036 (8.575)***	0.060 (3.189)***
Raw materials <sup>13</sup>	0.113 (6.653)***	0.111 (6.170)***	0.011 (2.616)***
Capital Sq.	0.045 (8.490)***	0.045 (8.879)***	0.111 (6.616)***
Labour Sq.	0.243 (19.62)***	0.243 (20.50)***	0.045 (9.599)***
Raw Mat. Sq.	0.077 (24.67)***	0.078 (24.21)***	0.243 (20.26)***
Cap. x Lab.	-0.021 (-4.021)***	-0.021 (-4.158)***	0.078 (22.57)***
Cap. x Raw Mat.	-0.018 (-5.253)***	-0.018 (-5.487)***	-0.021 (-4.001)***
Lab. X Raw Mat.	-0.061 (-11.03)***	-0.061 (-11.07)***	-0.018 (-5.746)***
D_pavitt_1	-0.185 (-4.552)***	-0.188 (-4.463)***	-0.187 (-4.344)***
D_pavitt_3	-0.213 (-5.400)***	-0.217 (5.016)***	-0.216 (-4.919)***
D_pavitt_4	-0.248 (-6.002)***	-0.251 (-5.847)***	-0.251 (-5.853)***
D_2003-2001	7.089 (265.4)***	7.082 (379.9)***	7.088 (275.01)***
D_1998-2000	-0.040 (-1.837)*	-0.040 (-2.033)**	-0.040 (-1.864)***
Selection Indicator	0.010 (0.503)		0.008 (0.415)
	Technical Efficiency variables		
Inv. ICT <sup>14</sup>	-1.412 (-35.06)***	-1.387 (-32.82)***	-1.398 (-49.25)***
Age	-0.031 (-6.495)***	-0.031 (-6.756)***	-0.031 (-5.891)***
D_group	-1.972 (-7.522)***	-1.966 (-7.455)***	-1.992 (-7.202)***
D_small	-13.30 (-29.53)***	-13.37 (-24.89)***	-13.40 (-22.70)***
D_medium	-14.27(-29.04)***	-14.36(-33.39)***	-14.40(-29.19)***
D_area_1	-14.01 (-28.45)***	-13.97 (-34.30)***	-13.92 (-27.54)***
D_area_2	-14.75 (-30.80)***	-14.71 (-36.65)***	-14.68 (-31.67)***
D_area_3	-15.68 (-37.90)***	-15.67 (-45.04)***	-15.63 (-31.71)***
D_pavitt_1	-15.50 (-27.75)***	-15.46 (-28.01)***	-15.40 (-21.50)***
D_pavitt_2	-14.64 (-24.75)***	-14.68 (-21.79)***	-14.61 (-20.14)***
D_pavitt_3	-14.52 (-26.34)***	-14.51 (-22.29)***	-14.44 (-19.99)***
D_2003-2001	15.23 (42.36)***	15.05 (48.65)***	15.08 (37.31)***
D_1998-2000	21.59 (91.81)***	21.62 (94.89)***	21.60 (96.51)***
Selection Indicator		-0.176 (-0.740)	-0.153 (-0.471)
Sigma-squared	43.92 (38.27)***	43.97 (39.81)***	43.96 (38.38)***
Gamma	0.996 (5958.2)***	0.996 (6191.20)***	0.996 (6189.9)***
Mean Efficiency	0.50	0.50	0.50
Nr of obs	12629	12629	12629
	Elasticities		
Capital	0.21	0.21	0.21
Labour	0.48	0.48	0.48
Raw Materials	0.14	0.14	0.14
Returns to scale	0.83	0.83	0.83

<sup>12</sup>\*\*\* indicates significance of 1%, \*\* at 5% and \* at 10%.

<sup>13</sup> Before taking the logs I was summed to raw materials since there were some firms with 0 values for these variables.

<sup>14</sup> Since there were some firms that did not invest in ICT before taking the logs I was summed to the investment in ICT.