CEIS Tor Vergata

RESEARCH PAPER SERIES

Working Paper No. 29 August 2003

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CEIS Tor Vergata - Research Paper Series, Vol. 10, No. 29 August 2003

ICT investment, productivity and efficiency: evidence at firm level using a stochastic frontier approach

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Abstract

We analyse the determinants of ICT investment and the impact of information technology on productivity and efficiency on a representative sample of small and medium sized Italian firms. In order to test the most relevant theoretical predictions from the ICT literature we evaluate the impact of investment in software, hardware and telecommunications of these firms on a series of intermediate variables and on productivity. Among intermediate variables we consider the demand for skilled workers, the introduction of new products and processes and the rate of capacity utilisation. Among productivity measures we include total factor productivity, the productivity of labour, and the distance from the "best practice" by using a stochastic frontier approach.

Our results show that the effect of ICT investment on firm efficiency can be more clearly detected at firm level data by decomposing it into software and telecommunications investment. We find that telecommunications investment positively affects 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.

We interpret these results by arguing that ICT investment modifies the trade-off between scale and scope economies. While software investment increases the scale of firm operations, telecommunications investment creates a "flexibility option" easing the switch from a Fordist to a flexible network productive model in which products and processes are more frequently adapted to satisfy consumers' taste for variety.

Paper presented at the XII Villa Mondragone Conference on "Knowledge economy, information technologies and growth", held in Frascati, June 2000. We thank R.Cappellin, F. Daveri, W. Greene, D. Jorgenson, M. Kiley, L. Linch, C. Milana and all participants to the Conference for helpful comments and suggestions. The usual disclaimer applies.
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1. Introduction

The relationship between information and communication technology (from now on also ICT)[1] and productivity has long been debated over the past three decades. In the 1980s and in the early 1990s, empirical research generally did not find relevant productivity improvements associated with ICT investment (Strassmann, 1990; Lovemann, 1988; Bender, 1986; Franke, 1987; Roach, 1989). Various rationales have been suggested to explain this paradox such as the limit of using simple bivariate correlations between aggregate productivity and aggregate ICT capital stock (Lehr-Licthemberg, 1999), the potential negative effect of augmented variety on productivity (Barua et al., 1991), the delayed effect of ICT investment on productivity gains and its dependence on network externalities and on changes in the complementary infrastructure (David, 1990).

More recently, as new data were made available and new methodologies were applied, empirical investigations have found evidence that ICT is associated with improvements in productivity, in intermediate measures and in economic growth (Oliner and Sichel, 1994; Lehr-Licthemberg, 1999; Sichel, 1997; Brynjolfsson and Hitt, 1996).

A first direction for improving this last vintage of empirical approaches is a disaggregation of the impact of ICT into the contributions of components with different effects and characteristics (such as software, hardware and telecommunications). A second direction is the implementation of the estimating approach usually based on two-stage estimation procedures (production function and then, separately, an estimation in which the dependent variable is the residual from the first equation) which inconsistently assume the independence of the inefficiency effects in the two estimation stages and are likely to be inefficient.

The paper follows these two directions showing that microfounded estimates of efficiency at firm level confirm the result of a positive and significant impact of ICT investment on productive

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[1] Information Technology is defined by the US Bureau of Economic Analysis as: "Office, computing and accounting machinery". As many researchers do we add to it communication equipment, software and related services.

efficiency found by the most recent literature. The paper also shows that it is possible to understand better the impact of ICT investment by decomposing it into software and telecommunications. Software investment has scale effects by increasing labour productivity, the demand for high skilled workers and the overall firm productive efficiency for a given amount of inputs. Telecommunications investment has scope effects by positively affecting the creation of new processes or products. The combination of these two effects, increases productive efficiency and utilisation capacity.

In the theoretical section of the paper these results are explained in the framework of the real option theory. We argue that changes in products and processes induced by ICT investment, reduce lags between knowledge of highly variable consumer tastes and final production.[2] These changes generate a flexibility option which, at any instant in time, gives the opportunity to delay the decision to invest in additional capacity, on the one side, and makes the decision to modify products and processes more likely, on the other side, thereby generating the observed effects on productivity and capacity utilisation.

The paper is divided into five sections. The second section presents descriptive empirical evidence on the intensity of investment in hardware, software and telecommunications in a representative sample of more than 4,000 Italian firms between 1995 and 1997 showing how ICT investment is affected by industry, geographical and qualitative firm characteristics. The third section outlines the four hypotheses to be tested. The fourth section analyses the effects of ICT investment on several intermediate variables such as capacity utilisation, new product/process introduction and hiring rates of high skilled workers at firm level. The fifth section presents several estimates which evaluate the association between ICT investment and the distance from the "efficient frontier."

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[2] To find significant examples which support this hypothesis see analyses of the effects of the creation of call centers (Aksin- Harker, 1999), of the introduction of CAD/CAM (Computer Aided Design and Computer Aided Manufacture) Milgrom- Roberts, 1988), and ERP (Enterprise Resource Planning) (Clausen-Koch, 1999; Wright-Burns, 1997). All these changes in the organisation of the productive process and customer relationship are induced by ICT investment.

2. Descriptive empirical findings on ICT investment intensity in Italy

We evaluate the intensity of ICT investment and its impact of various productivity measures using the Mediocredito Survey. The Survey includes a sample of more than 4,000 firms drawn from the whole set of Italian manufacturing firms. The sample is stratified according to industry, geographical and dimensional distribution of Italian firms for firms from 11 to 500 employees. It is by census for firms with more than 500 employees. For a subsample of 4,404 firms both qualitative and quantitative data (balance sheets for the 1995-1997 period) are collected. [3] Qualitative data provide, among other things, information about internationalisation, R&D investment, and successful introduction of products and processes.

Descriptive features of this sample illustrate some important characteristics of ICT investment in Italy (Table 1). The average ICT cumulative investment per employee in the sample period is 7 million liras. Per capita ICT investment is on average: i) more than a half lower in firms located in the South; ii) much higher in firms located in the North-East; iii) substantially higher for small firms and (as expected) for firms in the Specialised industries according to the Pavitt classification (mechanical equipment and mechanical materials).

By disaggregating ICT investment into hardware, software and telecommunications components we find that: i) software and hardware investment per employee in North-East (in the South) is almost double (half) as much as the national average; ii) software and hardware investment intensity is also

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[3] All balance sheet data in the Mediocredito database are accurately checked. Balance sheet data come from CERVED which has the official information from the Italian Chambers of Commerce and is currently the most authoritative and reliable source of information on Italian companies. Qualitative data from questionnaire are based on responses from a representative appointed by the firm collecting information from the relevant firm division. The questionnaire has a system of controls based on "long inconsistencies", namely inconsistencies between answers to questions placed at a certain distance in the questionnaire (i. e. responses use of government subsidies (export subsidies) are matched with responses on the exact composition of the flow of funds available for investment - internal finance, debt finance, grants, soft loans. – (on the share of exported net sales).
In case of inconsistent information the firm is subject to a second phone interview. Firms which do not provide reliable information after being recontacted are excluded from the sample. A supplementary list of 8000 firms is built for each of the three year surveys in order to avoid that exclusions, generated by nonresponses or inaccuracies in questionnaire responses, alter the sample design. Substitutions follow the criteria of consistency between the sample size and the population of the Universe.

relatively higher in Specialised industries and in R&D investing firms. The pattern of telecommunications investment is quite different. Intensity is higher in larger firms and in firms affiliated to groups and its geographical distribution is not so different across macroareas.

3. Four hypotheses on the impact of ICT investment: theoretical rationales and empirical tests

To investigate the effects of ICT investment we disaggregate it into different components and test their impact on productivity at firm level. The survey of the existing literature and the theoretical analysis lead us to formulate 4 hypotheses which we briefly explain and test in the following sections of the paper.

Hypothesis 1: investment in software increases the demand for skilled labour

This hypothesis has been already put forth by Roach (1991), Berndt et al. (1992) and Stiroh (1998) which argue that, even though ICT may substitute for labour, it also increases white collar productivity and hiring rates.

This proposition is the obvious outcome of cost minimisation under the assumption that an increase in the stock of ICT capital raises more the marginal productivity of skilled vis-à-vis that of unskilled labour. In this case, if the market for skilled labour is competitive, or if skilled labour wage is not too upward sloping in the number of skilled workers hired, only an increase in the number of skilled workers may restore the equilibrium condition which states that the ratio of wages between two factors must equal the ratio between their marginal productivities. Descriptive evidence does not contradict our hypothesis as software investing firms have an average yearly hiring rate of 0.6 per cent against a 0.3 per cent of the rest of the sample.

In testing econometrically our hypothesis, we use a Tobit model and evaluate the significance of coefficients with percentile and bias corrected bootstrapping techniques since the dependent variable is clearly nonnormal (Table A1.1) and left censored,.[4]

By estimating our model we empirically find a positive and significant effect of software investment on the demand for high skilled workers[5] which supports our theoretical hypothesis (see Table A1.2 in the Appendix). This effect is significant net of the relationship that other controls have on the dependent variable (the positive and significant impact of size, export capacity, government subsidies and industrial group affiliation).

Hypothesis 2: investment in telecommunications positively affects the introduction of new products or processes

Previous papers argue that ICT investment has a positive effect on productive variety (Barua-Kriebel-Mukhopadhyay, 1991). We show here that this hypothesis is confirmed but that the increased variety effect must be attributed to telecommunications only and not to software and hardware investment. If telecommunications investment (such as the introduction or implementation of e-commerce, intranet and internet communication and network production) allows the firm to know in real time consumer tastes and to adapt more quickly its productive process to satisfy consumers' taste for variety, the introduction of new processes and products should be positively affected by it. Descriptive evidence strongly supports this hypothesis as 69 percent of telecommunication investing firms declare they have introduced new products against 30 percent of the rest of the sample. Empirical results show that investment in telecommunications for firms affiliated to groups is positively and significantly related to the decision to introduce new products (Table A1.2). The interesting finding is that the effect is not significant for those firms which invest in telecommunications but are not part of a group. The interpretation is that the scope

[4] In a previous version of the paper (Becchetti et al.,2001) we extend the set of regressors to include a number of controls larger than that considered here. Our results on the effects of ICT on the dependent variable are unchanged and

and flexibility effect of this kind of ICT investment can be achieved only in an integrated network productive system which is typical of industrial groups. Logit results also show that investment in hardware (R&D investment) seem to affect negatively (positively) the dependent variable. The negative impact of hardware may be interpreted by considering that hardware investment is mainly related to an individual and specific production process, entails much more sunk costs and reduces flexibility and opportunities for introducing new processes. When we consider as a dependent variable the introduction of both products and processes the positive impact of telecommunications investment is confirmed. An interesting result is also the different effect on the dependent variable of investment subsidies - negative - and tax allowances - positive - which shows that when government support - as it is in the case of tax allowance - is not related to a specific investment in physical capital (and, often, to the renovation of the existing capital stock) it increases flexibility and capacity of introducing new products or processes.

Hypothesis 3: the investment in Information and Telecommunication Technology increases the value of the firm by adding a flexibility option whose effect is that of increasing average capacity utilisation .

The hypothesis of a positive relationship between capacity utilisation and ICT has been formulated by Barua-Kriebel-Mukhopadhyay (1991). We find support for it on our data and provide a theoretical rationale by using a simple dynamic programming example.

We may think of an investment in telecommunications as having a B2C (business to consumer) and a B2B (business to business) effect. The first enables producers to know in real time consumer tastes and the demand for differentiated products of the firms (consider for instance the recent development of "call centers" as an emerging marketing tool in which ICT allows to intensify

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are available upon request .
[5] We use the ratio of high skilled (graduated) workers hired to total firm employees as a dependent variable.

contacts between a firm and its consumers). The second allows, through internet and intranet communication, the reduction of production lags and informational asymmetries among subcontractors and component producers at different levels of the chain value (i.e. the creation of "digital auction markets" for specific product chains increases the number of participants, reduces transaction costs and reduces lags between the definition of new product characteristics adapting to changed consumer tastes and its availability to final consumers). In our model this creates for the ICT investing firm the possibility to invest and adapt production in the same period in which consumer tastes are known.

Consider therefore the decision to increase productive capacity to satisfy a potential increase in demand under uncertainty as a real option in a simple dynamic approach. If telecommunications investment, reduces lags between knowledge of current customer tastes and final production, it also has the effect of enlarging the time window in which the firm may adapt its capacity to satisfy market demand. Telecommunications investment therefore creates an option for flexibility transforming the investment in the capacity increase from a "now or never" investment into a decision which can be postponed. In this framework, for certain values of model parameters, the decision to wait is preferred to the decision to "invest now" in additional capacity by ICT firms. Given the ex post positive probability of the realisation of the negative state of nature, the non ICT firm will find herself with expected lower additional capacity, contrary to the ICT firm which can postpone the investment decision after the observation of the stock.

The following theoretical example may help to explain this point. Consider the case of an entrepreneur which must invest in additional capacity and has not invested in ICT. The entrepreneur knows that in t_1 there will be a taste shock which will affect the demand of the product generated with additional capacity. The model is in two periods.

Additional capacity will therefore yield to him extra revenues generated by the following process: X in t_0 and $X(1+g)$ in t_1 if the shock increases the demand for the product (with prob p) and $X(1-d)$ if the shock reduces the demand for the product (with prob $1-p$). The non ICT entrepreneur must decide to invest now because: i) either he has not the technology to know consumer tastes in real time (know in t_1 the realisation of the shock occurred in t_1) or ii) because its productive process cannot be adapted in t_1 (extra additional capacity cannot be added) to produce in t_1. On the contrary, the ICT entrepreneur may delay the investment since the availability of telecommunication technology has the above mentioned B2C (business to consumer) and B2B (business to business) effects. In our model this creates for the ICT investing firm the possibility to invest and adapt production in t_1 after knowing consumer tastes in the same period.

The value of its investment in extra capacity will be: $\Omega_{NIT} = \max\{V_0 - I, 0\}$ where $V_0=X+[X(1+g)p+X(1-d)(1-p)](1/(1+r))$ or $V_0=X+[X(1+p(g+d)-d)](1/(1+r))$. The entrepreneur which has invested in information and telecommunications technology may know in real time consumer tastes on its web site and has eliminated lags between changes in productive capacity and final production. Therefore the value of its investment changes into: $\Omega_{IT} = \max\left\{V_0 - I, \frac{E_0[F_1]}{1+r}\right\}$ where $E_0[F_1]=p*max[X(1+g)-I,0]+(1-p)*max[X(1-d)-I,0]$.[6] is the expected value today of the continuation value. The investment in ICT will therefore increase the value of the ICT investing firm by the flexibility option which is equal to W_{IT}-W_{NIT}. It is obvious then that there will be values of *g,d,p* such that: $0 < V_0 - I < \frac{E_0[F_1]}{1+r}$. If this condition holds the ICT entrepreneur will find it optimal to wait in t_0 and the non ICT entrepreneur will find it optimal to invest in additional capacity. As a result, capacity utilisation will be higher for the ICT entrepreneur in t_1 if the negative shock is realised (with probability (*1-p*)) since, with the negative shock, the additional capacity I is too much to produce just *X(1-d)*. The inequality holds when V_0-*I>0* (*NC_1*) if

$X+[X(1+p(g+d)-d)](1/(1+r))-I< [p*max[X(1+g)-I,0]+(1-p)*max[X(1-d)-I,0]] (1/(1+r))$

In choosing whether to postpone the investment the ICT entrepreneur therefore trades off the advantage from investing soon (the present cash flow from the investment in t_0 (X)) with the advantage from waiting and avoiding to invest under the bad state of nature in t_1 and from reducing the expected cost of the investment. Therefore if *X>Ir/(1+r),* it is convenient to wait only if the investment would give nonpositive returns in case the bad state of nature is realised. It is therefore clear that the value of the option to wait is increasing in the discount rate and - if the value of the project is non positive under the negative shock - in the size of the negative shock, while it is decreasing in the project value.

To check whether the same arguments hold in continuous time and with a slightly more complex stochastic process for returns from the project of investing in additional capacity, consider the following argument developed by following the standard Dixit-Pindick (1994) approach .

Let the return from investing in additional capacity follow the geometric Brownian motion: $dY = aYdt + sYdz$ where *dz* is the increment of a Wiener process so that *E[dz]=0* and *Var[dz]=dt*. Remember that *Y* represents the present value of the investment in additional capacity and therefore the discounted sum of cash flow from the investment at the time the investment itself is taken. Consider the payoff from investing now: $\Omega_{Yo} = \max\{Y_0 - I, 0\}$ and the payoff from holding the option to invest in the future $\Omega_Y = F(Y) = \max E\{(Y_T - I)e^{-rT}\}$ where T is the period in which the firm finally decides to expand its capacity. We are in the continuation region if $\Omega_Y > \Omega_{Yo}$. In this region the following no arbitrage condition holds: $rF(Y)dt = E[dF(Y)]$. On the left hand side we have the appreciation at the normal market return of a sum corresponding to the value of the option. On the right hand side we have the change in value of the option to wait in the same interval. By applying Ito's lemma, taking expectation and simplifying we get the following second order (homogenous-constant coefficient) differential equation: $F_t + aYF_Y + \frac{1}{2}s^2Y^2F_{YY} - rF = 0$.

The differential equation has the usual three boundary conditions:

F(0)=0 *(A2.1), F(Y*)=Y*-I* *(A2.2) , F'(Y*)=1* *(A2.3)*

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[6] Note that, from a mathematical point of view the flexibility option shifts the probability of the realisation of the state of nature before the max operator. In other terms, the advantage of postponing the investment decision is that the

The first is the obvious consequence of what happens to a geometric Brownian motion when $Y=0$. The second is the value matching condition, which implies that the gain from investing net of the opportunity cost is equal to the cost of investing. Finally (A2.3) is the smooth pasting condition requiring that not only levels but also first derivatives of the holding option and the termination payoff match at the optimum.

The trial solution which satisfies (A2.1) is $F(Y) = AV^{b1}$. By replacing this solution in (A2.2) and (A2.3) we find the usual values for A and Y^* with $Y^* = \frac{b_1}{b_1 - 1} I$. To solve for the value of b_1 we replace the trial solution in the second order differential equation and simplify to obtain: $F_t + aYF_Y + \frac{1}{2} s^2 b(b-1) + (r-d) - r = 0$. This second order equation gives two roots: $b_1 > 1$ and $b_2 < 0$. Given the range of values that b_1 can take the following inequality may hold: $Y^* < Y < I$. When Y takes values which respect this inequality the non ICT firm will invest in additional capacity but the ICT firm will find it optimal to wait. A subsequent fall in the value of the returns from the project will therefore generate the result of a lower capacity utilisation for the ICT firm.

$Y^* < Y < I$ may occur even in the case of a deterministic process similar to the previous one except for $s=0$. In this case in fact it is possible to find the time at which the option to increase productive capacity is exercised. We have in fact $\Omega_Y = \{(Ye^{-aT} - I)e^{-rT}\}$. After rearranging first order condition we get: $T^* = \max E\left\{\frac{1}{a}\log\left[\frac{rI}{(r-a)Y}\right], 0\right\}$. It is clear than that if Y is not too higher than I it is better to wait for the ICT firm while it is impossible to do it for the non ICT firm.

Empirical results are consistent with our hypothesis on the effects of telecommunications investment on capacity utilisation. The interesting point is that the effect is positive only when firms are part of a group. This may be interpreted by saying that the crucial factor in generating the flexibility option is the network productive organisation. In the language of our theoretical model the critical factor is not just the capacity of knowing consumer tastes in real time (B2C effect) but

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decision can be taken after the state of nature in t_1 has been observed.

mainly the capacity of a more flexible productive organisation (B2B effect) which reduces lags between knowledge of consumers' taste for variety and the final production of a complex diversified range of products which assemble different components.

Hypothesis 4: investment in software increases the average productivity of labour.

The effect of software investment on average labour productivity is the consequence of hypothesis 1 as new workers are hired, the new software technology increases the marginal productivity of each individual worker and average labour productivity is higher.[7]

Given the nonnormal distribution of the dependent variable (Table A 1.3) we evaluate the effect of our set of regressors on two points of the distribution of the dependent variable (conditional mean and conditional median). Empirical results on the determinants of labour productivity seem consistent with our theoretical conclusions. In the estimate with all controls software and telecommunications investments have the expected sign even though the impact of telecommunications is significant only on conditional mean and not on conditional median. On the other hand, hardware investment has no significant impact on the dependent variable.

This last result may seem puzzling at first sight. Software and hardware are two complementary factors which jointly determine the ICT endowment of a firm. It seems almost impossible that one of them functions without the other. We believe that there are at least three reasons which justify our result.

The first is that in Italy several laws exist *[Law 64, Law 488, Law 46/82(R&D program), Law 1329/65 (Sabatini program), Law 949/52 (SME program)]* providing soft loans or grants for buying hardware together with other investment goods but several times human resources do not possess

[7] Only with a wage which is insensitive to the total number of employees the marginal productivity of the last worker hired would be the same as before.

skills for operating them. It is therefore frequent to see hardware which has been purchased for free with grants but is not used because there are no skills for operating it.

The second is that the same vintage of hardware investment may support different vintages of updated software (up to a certain limit). Therefore software needs more frequent renewal without which the productivity of hardware cannot be enhanced.

As a consequence of these two factors jointly considered it is likely that the positive effect on productivity is realized mainly when positive software investment indicates that the human capital is able to adopt and use the technology incorporated in the hardware and that the hardware potential is implemented with new and more powerful software.

A third explanation is represented by web hosting or housing practices. This indicates the habit of many small firms, [8] as those considered in the sample, of investing in software but not in hardware, renting a shelf in a mother company whose hardware houses the small company software**.** In this case the software-hardware complementarity vanishes and the software investment alone may generate productivity effects.

4. ICT investment and firm efficiency: a stochastic frontier approach

The empirical approach followed so far has the defect of not being rigorously microfounded. The stochastic frontier approach followed in the next section will amend this problem and test whether different types of ICT investment significantly affect the distance from the optimal production frontier in our sample. We estimate the impact of ICT investment on efficiency at firm level by

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[8] A 2000 Dresder Kleiner Benson Report (Web hosting /ASP, March 2000) indicates that the web hosting market has almost doubled every year between 1995 and 1997 and that 66 percent of surveyed firms indicated the lack of internal resources as the reason for this choice. The report also says that “managing storage area networking, and providing real time memory space, processing power, shared RM/ROM and transparent load balancing across several local points of presence is complex task. As servers need to be replicated in multiple geographic locations to move content closer to

using a traditional stochastic frontier approach (Battese and Coelli, 1995). In this model the inefficiency effects are expressed as an explicit function of a vector of firm-specific variables and a random error[9]

The first equation is a five input Cobb-Douglas production function and is specified as follows:

$$Y_{it} = a_0 + \sum_{j=1}^{m-1} a_j * Ind_j + b_1 K_{it} + b_2 HSL_{it} + b_3 LSL_{it} + b_4 RM_{it} + b_4 II_{it} + v_{it} - u_{it} \quad (1).$$

Y is the log of real output of the i[th] firm at time t *(i=1,...,N; t=1,...,T); K* is the log of the capital stock evaluated at the replacement cost, *HSL*, *LSL*, *RM* and *II* represent additional inputs (and are respectively the log of high skilled and low skilled workers, raw materials and intermediate inputs). Since any industrial sector may have in principle a different production function we add to the specification *m-1* intercept dummies for 20 sectors aggregated on the basis of the four digit ISTAT-ATECO classification. This solution is not completely satisfactory as industry production functions may also differ in input marginal productivities. We therefore estimate the model separately for each industry for which we have enough degrees of freedom.[10] The v_{it} is a random variable which is assumed to be iid. $N(0, s_V^2)$, and independent of the u_{it}. The latter is a non-negative random variable which is assumed to account for technical inefficiency in production and to be independently distributed as truncation at zero of the $N(m_{it}, s_U^2)$ distribution. Finally, $m_{it} = z_{it}\mathbf{d}$, (2), z_{it} is a $p´1$ vector of variables which may influence the efficiency of a firm and **d** is an $1´p$ vector of parameters to be estimated.

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the customer, avoid congestion at single server location and reduce risk through physical network redundancies, the cost complexity of in-house hosting becomes untenable".

[9] This approach has been widely recognised to be superior to the two-stage estimation which inconsistently assumes the independence of the inefficiency effects in the two estimation stages. 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.

[10] Estimates with a simpler two input Cobb-Douglas production function for the overall sample with dummies accounting for differences in industry slopes have also been performed with results on the impact of ICT investment on productive efficiency which are not substantially different from those obtained with the five input aggregate and industry estimates. These additional estimates are available from the authors upon request.

Following Battese and Coelli (1993), we replace σ_V^2 and σ_U^2 with $\sigma^2=\sigma_V^2+\sigma_U^2$ and $\gamma=\sigma_U^2/(\sigma_V^2+\sigma_U^2)$. The log-likelihood function of this model is described in Battese and Coelli (1993).

The nonzero mean residual of the production function is regressed on a series of factors which are expected to affect efficiency:

$$u_{it} = \alpha_0 + \sum_{i=1}^{m-1} \alpha_i Ind_i + \sum_{k=1}^{n-1} \gamma_k Macroarea_k + \delta_1 Young + \delta_2 Old + \delta_3 Group + \delta_4 Csat + \\ + \delta_5 Qtnosep + \delta_6 Family + \delta_7 CSSA + \delta_8 Ration + \delta_9 \mathrm{R}ents + \delta_{10} \mathrm{Pr}esfi + \delta_{11} Innovat + \\ + \delta_{12} Cap + \delta_{13} ICT + \varepsilon_{it} \qquad (2)$$

First, we introduce factors traditionally considered in the literature (Hay-Liu, 1997; Nickell, 1996 and Nickell-Nicolitsas-Dryden, 1997) such as *CAP* (the degree of capacity utilisation), *RENTS* - ((profits before tax+depreciation+interest payments-cost of capital*capital stock)/value added) and *PRESFI* - interest payments/ (interest payment + cash flow). *IND*, *MACROAREA*, *SIZE*, *GROUP*, *QTNOSEP* and *FAMILY* are specified as in Appendix 1.

We then add two dummies (*OLD, YOUNG)* respectively picking up the older and the younger 20 percent of sample firms. An additional control (which we expect to be positively related to productive efficiency) is represented by *CSAT* and *CSSA*, two dummies respectively picking up firms monitoring customer satisfaction and firms which created sale structures abroad.[11] *INNOVAT* is a dummy for firms which successfully introduced new products or processes. Finally, *ICT* is the average ICT investment per employee.

The model is estimated as a cross-section in which all variables are expressed as three year averages. We adopt two different specifications. In the first ICT investments are considered jointly,

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[11] The literature investigating the relationship between efficiency and internationalisation usually finds a two-way positive relationship between internationalisation and productivity (Aw-Hwang, 1995; Clerides-Lach-Tybout, 1998 and Becchetti-Santoro, 2000). The variable is therefore an important control to be considered in order to avoid omitted variable biases.

while in the second they are disaggregated into software, hardware and telecommunications investment per employee.

On the whole the model seems to fit well our data and the presence of technical inefficiencies is supported by the positive and significant gamma coefficient (Table 3).

Estimate results show that aggregate ICT investment has a positive and significant effect on firm efficiency and that software has a positive (negative) effect when individually considered. Telecommunications investment has a weakly significant negative effect on efficiency. These findings show the existence of a symmetry between effects of ICT inputs on average labour productivity and on productive efficiency for a given level of inputs (Table A1.2).

The effect of telecommunication investment may seem surprising at first sight. We must consider though that in our previous hypotheses we argued that telecommunications investment extends the window in which the decision to increase productive capacity may be taken and gives firms not only the opportunity to expand capacity, but also to change products and processes to satisfy consumers taste for variety. If this is true telecommunications investing firms are more likely, at any instant of time, to shift firm activity to new products or processes by paying, though, when this decision is taken, the cost of reduced productivity of labour inputs which need to be retrained because of these changes (Kyley, 1999). This temporary negative effect should be offset by quality improvement generated by the introduction of new products and processes. If we measure the impact of telecommunication investment on measures of output not adjusted for quality the negative effect is likely to prevail.

Other controls give expected results. Firms located in the South, older firms and firms which declared to be credit rationed are significantly less efficient than average consistently with previous findings (Becchetti-Santoro, 2000). The result on rents is consistent with all the traditional literature on the effects of competition on efficiency.[12] The hypothesis that financial pressure increases

[12]According to it, competition has positive effects on efficiency (Short, 1994; Nickell, 1995; Vickers, 1995): i) by making it easier for owners to compare managerial performance with that of competitors; ii) by increasing the

managerial discipline (Jensen, 1986 and 1988; Aghion et al., 1995) is supported by our data only in the extended specification in which ICT investment is disaggregated into its three different components. Industry estimates show that the aggregate significance of the effect of ICT investment is determined by the behaviour of some and not of all considered sectors (Table 3). Estimates have been performed only for those industries (7 out of 19) for which we dispose of enough observations. The ICT coefficient significantly affects productive efficiency in five industries (Mechanical materials, Mechanical Equipment, Textile, Wood and Wooden Furniture, Paper and Printing) while in the other two (Metal Products, Food and Beverages) is not significant.

5. Conclusions

Simple intuition from experience in various professional fields (including the academia) suggests that the increase in productivity from an improvement in software technology (more powerful word processing and printing, etc.) is positively related to the skills of the labour inputs. In the same way, an improvement in telecommunications techology (such as the opportunity of internet or intranet networking, the introduction of e-mail, e-commerce, etc.) increases the inflow of available information thereby generating a flexibility option which will make more expensive and which will delay irreversible decisions such as new investments. This option will generate at the same time the opportunity to differentiate more quickly processes and products in order to satisfy consumers' taste for variety.

We therefore expect that, at any instant of time, a firm investing in telecommunications will delay investment in additional capacity and introduce new products and processes with a higher probability.

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advantage of higher efficiency under the form of cost reductions as the latter are more profitable under competition where demand elasticities are higher; iii) by leading managers to work harder in order to avoid bankruptcy which is more likely to occur in a tight market (Schmidt, 1996; Aghion-Howitt, 1996).

What we should observe therefore is an increase in the demand for skilled workers and in average labour poductivity after a software investment and an increase in capacity utilisation together with an increase in the introduction of new products and processes after a telecommunications investment.

These results open interesting directions for future research. Which is the combined effect of higher productivity and reduced investment intensity generated by the option to delay on the rate of growth ? Is the volume of high-tech investment socially optimal and, if not - considered that increased capacity utilisation must be related with a lower rate of growth of the physical capital stock and considered the positive externality of this type of investment on the rest of the economy -, which measures can be taken to reduce the incentive of high-tech firms to delay?

We think that answers may be found on fiscal and monetary policies and on the governance of financial markets and that the different ability to implement measures in these three directions is significantly affecting the capacity of different countries of translating benefits of the new economy into higher rates of growth.

Table 1 Descriptive findings on the determinants of ICT investment (95-97 ICT investments per employee - millions of liras)

ICT investment per employee	South and isles		Centre		North-West		North-East		ITALY	
	N.of obs	Mean	N. of obs	Mean	N. of obs	Mean	N. of obs	Mean	N. of obs	Mean
All firms	338	2.87	354	6.05	1386	5.42	802	12.06	2980	7.16
Small size	188	3.00	315	4.65	750	7.23	457	19.57	1710	9.59
Large size	86	2.46	80	13.67	413	3.25	208	3.48	787	4.28
Scale sectors	100	2.21	129	6.43	413	10.22	205	4.29	847	7.26
Traditional sectors	163	2.65	223	2.81	483	2.89	302	2.79	1171	2.82
Specialised sectors	37	4.27	80	4.91	424	3.64	264	31.47	805	12.92
R & D investmenting firms	88	4.53	178	8.77	607	5.98	333	25.23	1206	11.60
Subsidised firms	241	2.60	210	9.40	609	3.20	350	3.93	1410	4.20
Variable	**South & isles**		**Centre**		**North-West**		**North-East**		**ITALY**	
Telecommunication investment per employee	N. of obs	Mean	N. of obs	Mean	N. of obs	Mean	N. of obs	Mean	N. of obs	Mean
All firms	333	0.151	443	0.258	1363	0.149	792	0.152	2931	0.167
Small size	186	0.148	304	0.145	737	0.110	449	0.128	1676	0.126
Large size	84	0.190	80	0.789	404	0.206	207	0.191	775	0.261
Scale sectors	98	0.140	126	0.081	405	0.151	201	0.210	830	0.153
Traditional sectors	160	0.129	218	0.081	476	0.116	300	0.104	1154	0.108
Specialised sectors	37	0.271	78	0.570	418	0.164	260	0.164	793	0.209
R & D investing firms	88	0.145	172	0.550	594	0.191	331	0.185	1185	0.238
Variable	**South & isles**		**Centre**		**North-West**		**North-East**		**ITALY**	
Hardware investment per employee	N. of obs	Mean	N. of obs	Mean	N. of obs	Mean	N. of obs	Mean	N. of obs	Mean
All firms	333	1.718	443	3.908	1363	2.811	792	8.207	2931	4.311
Small size	186	1.876	304	2.768	737	3.777	449	13.222	1676	5.914
Large size	84	1.304	80	9.867	404	1.675	207	1.728	775	2.494
Scale sectors	98	1.276	126	4.169	405	5.373	201	2.074	830	3.908
Traditional sectors	160	1.614	218	1.443	476	1.461	300	1.399	1154	1.463
Specialised sectors	37	2.507	78	4.735	418	1.858	260	21.642	793	8.437
R & D investing firms	88	2.569	172	5.823	594	3.275	331	17.057	1185	7.442
Variable	**South & isles**		**Centre**		**North-West**		**North-East**		**ITALY**	
Software investment per employee	N. of obs	Mean	N. of obs	Mean	N. of obs	Mean	N. of obs	Mean	N. of obs	Mean
All firms	333	1.022	443	1.982	1363	2.475	792	4.356	2931	2.744
Small size	196	0.997	304	1.824	737	3.361	449	6.513	1676	3.664
Large size	84	0.959	80	3.015	404	1.384	207	1.546	775	1.550
Scale sectors	98	0.776	126	2.273	405	4.782	201	1.997	830	3.253
Traditional sectors	160	0.946	218	1.310	476	1.320	300	1.291	1154	1.259
Specialised sectors	37	1.495	78	1.885	418	1.631	260	10.114	793	4.431
R & D investing firms	88	1.819	172	2.587	594	2.537	331	8.126	1185	4.052

Tab. 2. ICT investment and productive efficiency: a stochastic frontier estimate (1997 cross-section estimate)

Production Function Variables				
	Coef.	t-ratio	Coef.	t-ratio
Constant	3.703	7.326	3.870	7.591
Ln(K)	0.142	9.553	0.139	9.126
Ln(HSL)	1.800	3.443	1.674	3.226
Ln(LSL)	1.452	2.032	1.383	1.930
Ln(RM)	0.119	10.812	0.122	11.272
Ln(II)	0.144	14.506	0.139	13.576
Ind1	0.345	2.919	0.317	2.158
Ind2	0.067	0.546	0.379	1.637
Ind3	0.252	1.018	0.236	0.872
Ind4	-0.186	-1.686	-0.258	-1.855
Ind5	-0.095	-0.805	-0.196	-1.317
Ind6	0.117	0.785	0.048	0.280
Ind7	-0.163	-1.319	-0.182	-1.235
Ind8	-0.486	-2.574	-0.546	-2.783
Ind9	-0.195	-1.276	-0.195	-0.913
Ind10	0.450	2.231	2.856	4.865
Ind11	-0.164	-1.391	-0.216	-1.433
Ind12	-0.189	-1.436	-0.279	-1.807
Ind13	-0.223	-2.064	-0.300	-2.153
Ind14	-0.322	-2.173	-0.400	-2.450
Ind15	-0.204	-1.313	-0.309	-1.814
Ind16	-0.544	-3.450	-0.631	-3.862
Ind17	-0.283	-2.432	-0.395	-2.638
Ind18	-0.437	-1.900	-0.393	-1.030
Ind19	3.895	4.307	3.588	5.000

Technical Efficiency Variables				
	Coef.	t-ratio	Coef.	t-ratio
Constant	-1.371	-1.810	0.118	0.164
Ind1	-0.763	-2.385	-0.558	-1.827
Ind2	0.197	0.694	0.567	1.803
Ind3	0.085	0.153	0.044	0.091
Ind4	-0.658	-2.303	-0.612	-2.319
Ind5	-1.087	-2.186	-0.987	-2.484
Ind6	-0.311	-0.746	-0.389	-1.039
Ind7	-1.349	-2.401	-0.845	-2.077
Ind8	-1.498	-1.638	-1.071	-1.514
Ind9	-0.157	-0.440	-0.126	-0.342
Ind10	0.076	0.147	2.586	4.285
Ind11	-0.295	-1.002	-0.293	-0.979
Ind12	-0.258	-0.719	-0.444	-1.465
Ind13	-1.127	-2.752	-0.947	-2.808
Ind14	-0.868	-1.579	-0.814	-1.790
Ind15	-2.719	-2.367	-2.982	-2.666
Ind16	-2.993	-2.840	-3.157	-3.202
Ind17	-3.073	-2.911	-2.792	-3.016
Ind18	-1.016	-1.084	-0.489	-0.537
Ind19	3.793	3.803	3.117	4.181
North-West	0.263	1.531	0.124	1.254
North-East	0.337	1.890	0.167	1.571
South	1.087	5.177	0.623	5.281
Young	0.144	1.375	0.057	0.723
Old	0.411	4.217	0.231	3.294
Group	0.127	1.521	0.075	1.235
Csat	-0.060	-0.669	-0.023	-0.356
Qtnosep	-0.002	-1.263	-0.001	-0.923
Family	0.059	0.703	0.032	0.519
CSSA	-0.077	-0.883	-0.046	-0.737
Ration	0.569	2.829	0.391	2.803
Rents	0.019	10.607	0.016	9.085
Presfi	-0.007	-0.652	-0.009	-1.773
Innovat	-0.043	-0.399	-0.035	-0.510
Cap	0.944	1.552	0.118	0.164
ICT investment - aggregate	-0.005	-8.261		
Software investments			-0.081	-4.110
Hardware investments			0.006	1.059
Telecommunication investments			0.063	1.639
Sigma-squared	0.468	18.123	0.366	13.391
Gamma	0.566	12.923	0.481	8.728
Log L		1288.48		1265.78
N. of Obs.		1752		1736

Industry Legend

Ind1: Food, beverages, tobacco
Ind2: Textile, clothing
Ind3: Leather, shoes
Ind4: Wood and wooden furniture
Ind5: Paper and printing
Ind6: Chemicals
Ind7: Rubber and plastics
Ind8: Glass, ceramics
Ind9: Construction materials
Ind10: Metal extraction
Ind11: Metal products
Ind12: Mechanical materials
Ind13: Mechanical Equipment
Ind14: Electronics
Ind15: Electrical equipment
Ind16: Precision instruments and apparels
Ind17: Vehicles and vehicle components
Ind18: Energy
Ind19: Other manufacturing

Table 3 ICT investment and productive efficiency: synthesis of results from stochastic frontier estimates at industry level

	Obs.	Gamma	Sig.	IT	Sig
Food, beverages, tobacco	179	0.148	2.780	0.009	0.277
Textile, clothing	**244**	**0.844**	**2.572**	**-0.022**	**-2.265**
Wood and wooden furniture	**101**	**0.735**	**7.647**	**-0.253**	**-1.753**
Paper and printing	**97**	**0.364**	**2.559**	**-0.019**	**-4.681**
Metal products	159	0.560	6.168	0.010	0.173
Mechanical materials	**74**	**0.454**	**2.312**	**-0.075**	**-3.156**
Mechanical Equipment	**181**	**0.136**	**6.138**	**-0.027**	**-5.324**

We estimate the model only for those industries for which we have a sufficiently high number of observations (n>70). We use a four factor production function given that low skilled and high skilled labour are highly multicollinear. A few of the other regressors included in the general model presented in tab.2 are singled out on the basis of the VIF factor (VIF>10) which measures multicollinearity with the remaining independent variables. Detailed estimate results are collected in an Appendix available from the authors upon request.

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Appendix 1

To consider the impact of ICT investment on different dependent variables we formulate a comprehensive model with six types of general controls plus specific controls which may be relevant for the selected dependent variable.

The specification adopted is:

$$IO = a_0 + \sum_{i=1}^{m-1} a_i Ind_i + \sum_{j=1}^{p-1} d_j Pavitt_j + \sum_{k=1}^{n-1} g_k Macroarea_k + \sum_{l=1}^{d-1} a_l Identity_l + \sum_{s=1}^{w-1} g_s Finance_s + \sum_{r=1}^{z-1} g_r IPHC_r + \sum_{q=1}^{y-1} g_q ITV_q + e$$

(A1.1)

where *IO* is the selected intermediate variable (utilisation capacity, hiring rate of skilled workers, introduction of new products or processes, net sales per employee) measured in 1997. Given the distributions of these dependent variables (see Table A.1.1) we adopt a right censored Tobit model for utilisation capacity, a left censored Tobit model for the hiring rate of skilled workers, a Logit model for the introduction of new products or processes and least squares for net sales per employee. Since dependent variables are not normally distributed (see Table A 1.1) we estimate confidence intervals for regressors coefficients with bootsrapping techniques (we adopt the percentile method with 1000 replications). In the case of the net sales per employee estimate we check whether the impact of regressors are significant not only on conditional mean but also on conditional median.

Our groups of general controls are:

i)IND are *m-1* industry dummies based on a three-digit ATECO classification *(m=1,..,20)*,

ii)PAVITT are *p-1* macrosector dummies *(p=1,..,4)*, [13]

iii) MACROAREA are *n-1* macroarea dummies *(n=1,..,4)*,

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[13] These are three of the four Pavitt dummies (Scale, Specialised, High-Tech and Traditional sectors). We adopt both the Pavitt and the 21-sector extended classification since firms within the same sector often belong to different Pavitt

iv) IDENTITY (four variables): *SIZE* are firm's employees in 1995, *BIRTH* is the firm's year of establishment, EXPORT is a dummy for exporting firms, *GROUP* is a dummy which takes value of one for firms affiliated to groups (subsidiaries or parent companies) and zero otherwise.

vi) FINANCE (three regressors on the availability and costs of external and internal finance): *SUBSIDY* is a dummy indicating if the firm received soft loans, *AGEVOL* is a dummy for firms which received tax allowances in the 1995-97 period, *LEV* is the 1995 ratio of debt versus banks to total assets,[14]

vii) INNOVATION, HUMAN AND PHYSICAL CAPITAL (four controls for technological innovation): *INNOVAT* is a dummy taking value of one if the observed firm declares to have successfully innovated their products or processes, *R&DINV* is a dummy for firms with nonzero R&D investment in 1995, *QLWSK* is the 1995 share of low skilled workers (workers without a University degree) on total employees, *CAPAD* is capital intensity or the stock of physical capital per employee.

viii) ITV (vector of information technology variables): *ITXASOF*, *ITXAHAR*, *ITXATEL* and *ITXTELG* are respectively the 1995-1997 investment in software, hardware, telecommunications and telecommunications for firms participating to groups. All these variables are scaled for the total number of firm employees.

Results of estimates including all controls are shown in tab A1.2.

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macrosectors. The inspection of the correlation matrix shows that this choice does not create severe multicollinearity problems in the estimate. The correlation matrix is available from the authors upon request.

[14] In balance sheet data the following debt items are registered: i) debt versus banks; ii) debt versus partners; iii) debt versus group; iv) debt versus suppliers - customers anticipated payments; v) bonds. Items ii) and iii) should be considered as equity more than debt, because non individual firms are often participated with a share higher than 50%. Item iv) is commercial debt more linked to operating expenses than to investment financing. We use total assets and not equity capital as a scale variable because all firms are small and medium sized, not listed in the stock exchange and most of them family owned. As a consequence, equity capital is often a symbolic balance sheet item, extremely volatile and not representative of firm's stock of total assets.

Tab A.1.1 Percentile distribution and normality tests for dependent variables of econometric estimates in Tab. A1.2

Percentile	Fatad97	Dhsk	Cap97
10	133.572	0.000	0.70
20	169.263	0.000	0.70
30	200.000	0.000	0.80
40	231.250	0.000	0.80
50	267.653	0.000	0.85
60	309.989	0.000	0.90
70	369.003	0.000	0.90
80	468.196	0.000	0.95
90	637.343	0.011	1.00
100	19417.850	0.654	1.00
Mean	368.634	0.004	0.831
Obs	4445	3317	4309
Normality tests			
Shapiro-Wilk Z	19.472	18.109	12.020
P-value (reject the null)	0.9999	0.9999	0.9999
Shapiro Francia Z	4.966	6.565	4.385
P-value(reject the null)	0. 9999	0.9999	0.9999

Variable legend. Fatad97: Net sales per employee in 1997; Dhsk: Demand for high skilled workers in 1997; Cap: capacity utilisation in 1997.

Tab A1.2 The effect of ICT investment on intermediate and productivity variables

	Demand for high skilled workers (l.c. Tobit)		Introduction of new products		Introduction of new products and processes		Capacity utilisation (r.c.Tobit)		Net sales per employee (conditional mean)		Net sales per employee (conditional median)	
	Coef.	b.s.e.♦	Coef.	z	Coef.	Z	Coef.	b.s.e. ♦	Coef.	b.s.e.♦	Coef.	b.s.e.♦
Scala	-0.002	0.004	0.087	0.31	0.152	0.55	- 2.665	1.576	21.666	78.320	- 64.817	35.565
Special	0.0004	0.004	0.356	1.26	0.163	0.59	- 1.538	1.580	11.334	74.819	- 47.177	37.296
Tradiz	- 0.008	0.004*	- 0.121	- 0.43	- 0.141	- 0.51	- 3.331	1.555	6.034	70.330	- 45.919	40.119
Novest	0.009	0.004**	0.054	0.31	- 0.075	- 0.42	- 1.243	1.141	27.020	57.137	- 6.571	27.458
Nest	0.013	0.005*	- 0.064	-0.33	- 0.252	- 1.28	- 1.088	1.236	31.056	90.327	-19.372	27.297
Sud	0.001	0.006	- 0.052	- 0.20	0.077	0.29	- 4.102	1.728**	- 127.675	99.829	-21.342	31.217
Size	0.000001	0.000003**	0.0002	1.72	0.002	1.86	0.002	0.001**	0.001	0.035	0.013	0.019
Birth	-0.00005	0.00005	0.002	0.93	0.004	1.42	-0.047	0.019**	- 0.093	0.699	- 0.202	0.298
Export	0.012	0.005**	0.323	1.98	0.229	1.35	0.019	1.009	- 125.039	108.294	19.991	21.523
Group	0.016	0.003**	- 0.074	- 0.53	0.144	1.09	0.072	0.792	64.302	29.655*	38.224	15.219**
Subsidy	-0.003	0.004	- 0.562	- 1.92	- 0.654	- 2.26	1.849	1.836	0.073	50.814	3.421	29.887
Agevol	0.013	0.005**	0.773	2.61	0.951	3.27	-1.450	1.810	- 111.204	63.409*	- 21.300	29.959
Lev	0.001	0.006	- 0.390	- 1.16	- 0.201	- 0.58	6.354	2.254**	608.855	174.171**	220.900	45.383**
Innovat	0.001	0.003					- 1.420	0.950	-7.295	37.403	- 13.553	23.448
Rdinv	0.004	0.002	0.963	8.13	0.931	7.50	- 0.861	0.772	47.222	52.118	- 24.924	13.405*
Qlwsk	0.410	0.217**	4.765	1.18	2.697	0.95	- 25.219	23.051	253.843	1051.665	1384.187	1014.63*
Capad	-	0.00001	- 0.00001	-19.62	- 0.001	- 24.74	0.0001	0.003	3.725	1.608**	1.226	0.184**
Amm	0.002	0.008					1.376	2.246				
Itxasof	0.0008	0.0005**	- 0.025	- 0.66	- 0.019	- 0.51	0.043	0.145	56.410	33.748*	13.771	7.851**
Itxahar			- 0.074	- 2.68	- 0.037	- 2.31	-0.049	0.144	- 2.542	16.293	- 1.702	7.394*
Itxatel	0.004	0.004	0.401	0.259	0.777	3.26	- 1.829	1.597	- 118.225	82.019*	- 10.341	20.936
Itxtelg	- 0.003	0.004*	1.042	2.36			2.814	1.806**				
Cons	-0.063	-6.67**	- 1.222	- 3.25	- 1.649	- 4.34			- 156.309	225.094*	163.842	52.373**
χ^2		222.6		Wald		Wald		58.41		F 2.47		
R sq.		- 0.45		0.10		0.10		0.01		0.22		0.10
N. of obs		1420		1497		1497		1454		957		957

♦ Bootstrap standard error

** *significant at 95% under the bias-corrected and percentile approach adopted to compute confidence intervals.*

* *significant at 95% under the bias-corrected approach adopted to compute confidence intervals.*

\- *not included for multicollinearity problems. For industry legend see tab. 2.*

Industry dummy results are omitted and available upon request.

Appendix 2 (not to be published) - Detailed results of stochastic frontier estimates at industry level)

The first equation is a five input Cobb-Douglas production function and is specified as follows:

$$Y_{it} = a_0 + b_1 K_{it} + b_2 L_{it} + b_3 RM_{it} + b_4 II_{it} + v_{it} - u_{it} \qquad (1).$$

Y is the log of real output of the i[th] firm at time t *(i=1,...,N; t=1,...,T); K* is the log of the capital stock evaluated at the replacement cost, L, RM and II represent additional inputs (and are respectively the log of the number of workers, raw materials and intermediate inputs). The v_{it} are random variables which are assumed to be iid. $N(0,s_V^2)$, and independent of the u_{it} . The latter are non-negative random variables which are assumed to account for technical inefficiency in production and are assumed to be independently distributed as truncations at zero of the $N(m_{it},s_U^2)$ distribution where $m_{it} = z_{it}d$, (2), z_{it} is a *p´1* vector of variables which may influence the efficiency of a firm; and ***d*** is an *1´p* vector of parameters to be estimated.Following Battese and Coelli (1993), we replace s_V^2 and s_U^2 with $s^2=s_V^2+s_U^2$ and $g=s_U^2/(s_V^2+s_U^2)$. The log-likelihood function of this model is described in Battese and Coelli (1993).The nonzero mean residual of the production function is regressed on a series of factors which are expected to affect efficiency:

$$\begin{aligned} u_{it} = {} & a_0 + \sum_{k=1}^{n-1} g_k Macroarea_k + d_1 Young + d_2 Old + d_3 Group + d_4 Csat + \\ & + d_5 Qtnosep + d_6 Family + d_7 CSSA + d_8 Ration + d_9 \mathrm{R}ents + d_{10} \mathrm{P}resfi + d_{11} Innovat \qquad (2) \\ & + d_{12} Cap + d_{13} ICT + e_{it} \end{aligned}$$

where *RENTS* = ((profits before tax+depreciation+interest payments-cost of capital*capital stock)/value added) and *PRESFI* = interest payments/ (interest payment + cash flow). *IND, MACROAREA, SIZE, GROUP, QTNOSEP* and *FAMILY* are specified as in Appendix 1. *OLD, YOUNG* respectively picking up the older and the younger 20 percent of sample firms. *CSAT* and *CSSA*, two dummies respectively picking up firms monitoring customer's satisfaction and firms which created sale structures abroad. *INNOVAT* is a dummy for firms which succesfully introduced new products or processes. Finally, *ICT* is the average ICT investment per employee.

Tab. A2.1 ICT investment and productive efficiency: a stochastic frontier estimate (1997 cross-section estimate)

Food and Beverages

Production Function Variables			Technical Efficiency Variables		
	Coef.	t-ratio		Coef.	t-ratio
Constant	4.635	6.571	Constant	0.150	0.164
Ln(K)	0.227	1.901	North-west	-0.001	-0.002
Ln(L)	0.432	0.500	North-east	0.211	0.238
Ln(raw materials)	0.057	1.956	South	0.058	0.088
Ln(Intermediate products)	0.087	3.295	Young	-0.053	-0.063
			Old	-0.151	-0.274
			Group	-0.189	-0.174
			Csat	-0.127	-0.184
			Qtnosep	-0.012	-0.768
			Family	0.056	0.058
			CSSA	-0.116	-0.152
			Ration	-0.154	-0.136
			Rents	-0.006	-0.017
			Presfi	-0.135	-0.121
			Innovat	0.253	0.335
			Cap	0.150	0.164
			ICT	0.009	0.277
			Sigma-squared	0.299	4.266
			Gamma	0.149	2.780
			Log L		1.341E+08
			N of obs		179

Tab. A2.2 ICT investment and productive efficiency: a stochastic frontier estimate (1997 cross-section estimate)
Textile and clothing

Production Function Variables			Technical Efficiency Variables		
	Coef.	t-ratio		Coef.	t-ratio
Constant	5.748	8.985	Constant	1.170	2.574
Ln(K)	0.183	5.101	North-west	0.302	3.122
Ln(L)	-0.235	- 0.300	North-east	0.163	1.310
Ln(raw materials)	0.130	4.177	South	0.477	3.202
Ln(Intermediate products)	0.221	8.145	Young	-0.070	- 0.755
			Old	0.233	2.922
			Group	0.033	0.370
			Csat	0.147	1.684
			Qtnosep	0.0002	0.122
			Family	-0.024	- 0.330
			CSSA	-0.003	- 0.043
			Ration	0.558	2.454
			Rents	0.013	1.314
			Presfi	-0.004	- 0.759
			Innovat	-0.027	- 0.245
			Cap	0.295	0.955
			ICT	-0.023	- 2.658
			Sigma-squared	0.212	10.023
			Gamma	0.845	2.572
			Log L		1.532E+08
			N of obs		244

Tab. A2.3 ICT investment and productive efficiency: a stochastic frontier estimate (1997 cross-section estimate)
Wood and wooden furniture

Production Function Variables			Technical Efficiency Variables		
	Coef.	t-ratio		Coef.	t-ratio
Constant	8.268	13.779	Constant	-0.097	- 0.099
Ln(K)	0.144	2.898	North-west	-0.044	- 0.060
Ln(L)	-5.148	- 6.047	North-east	-0.054	- 0.088
Ln(raw materials)	0.096	2.332	South	0.320	0.399
Ln(Intermediate products)	0.108	2.116	Young	0.768	1.060
			Old	-0.018	- 0.022
			Group	0.659	0.849
			Csat	0.398	0.546
			Qtnosep	0.017	2.013
			Family	-0.178	- 0.280
			CSSA	-0.092	- 0.175
			Ration	-0.912	- 0.870
			Rents	0.018	1.587
			Presfi	0.239	2.215
			Innovat	-0.020	- 0.026
			Cap	-1.698	- 1.785
			ICT	-0.254	- 1.754
			Sigma-squared	0.417	2.794
			Gamma	0.736	7.647
			Log L		5.298E+07
			N of obs		101

Tab. A2.4 ICT investment and productive efficiency: a stochastic frontier estimate (1997 cross-section estimate)
Metal products

Production Function Variables			Technical Efficiency Variables		
	Coef.	t-ratio		Coef.	t-ratio
Constant	5.040	7.546	Constant	-1.186	-1.084
Ln(K)	0.182	3.097	North-west	0.286	0.459
Ln(L)	-0.922	-1.037	North-east	-0.687	-0.891
Ln(raw materials)	0.135	3.307	South	1.039	1.338
Ln(Intermediate products)	0.101	2.947	Young	0.402	0.484
			Old	1.342	1.680
			Group	0.462	0.881
			Csat	-1.558	-2.913
			Qtnosep	-0.002	-0.221
			Family	0.756	0.920
			CSSA	0.471	0.801
			Ration	1.306	1.408
			Rents	-0.018	-1.082
			Presfi	-0.204	-1.797
			Innovat	-0.779	-0.986
			Cap	0.138	0.156
			ICT	0.011	0.174
			Sigma-squared	0.495	4.319
			Gamma	0.560	6.168
			Log L		1.138E+07
			N of obs		159

Tab. A2.5 ICT investment and productive efficiency: a stochastic frontier estimate (1997 cross-section estimate)
Mechanical Materials

Production Function Variables			Technical Efficiency Variables		
	Coef.	t-ratio		Coef.	t-ratio
Constant	1.721	1.380	Constant	0.478	0.658
Ln(K)	0.150	2.285	North-west	-0.335	-1.413
Ln(L)	3.832	2.316	North-east	-0.547	-2.348
Ln(raw materials)	0.184	4.641	South	n.i.	n.i
Ln(Intermediate products)	0.244	4.367	Young	0.694	4.008
			Old	0.127	1.067
			Group	0.194	1.767
			Csat	0.119	0.994
			Qtnosep	n.i.	n.i
			Family	-0.324	-3.026
			CSSA	-0.175	-1.548
			Ration	n.i.	n.i
			Rents	0.012	1.487
			Presfi	0.003	0.714
			Innovat	0.228	1.313
			Cap	0.478	0.658
			ICT	-0.075	-3.156
			Sigma-squared	0.122	4.374
			Gamma	0.455	2.312
			Log L		2.264E+07
			N of obs		74

Tab. A2.6 ICT investment and productive efficiency: a stochastic frontier estimate (1997 cross-section estimate)
Mechanical Equipment

Production Function Variables			Technical Efficiency Variables		
	Coef.	t-ratio		Coef.	t-ratio
Constant	6.501	11.334	Constant	-0.124	- 0.413
Ln(K)	-0.013	- 0.364	North-west	n.i.	n.i.
Ln(L)	-2.308	- 2.763	North-east	-0.148	- 1.953
Ln(raw materials)	0.123	4.814	South	-0.016	- 0.073
Ln(Intermediate products)	0.163	6.057	Young	0.438	4.322
			Old	0.155	1.563
			Group	0.146	1.670
			Csat	0.045	0.492
			Qtnosep	0.055	0.528
			Family	-0.069	- 0.670
			CSSA	-0.005	- 3.256
			Ration	-0.760	- 5.372
			Rents	0.010	1.150
			Presfi	0.198	2.731
			Innovat	-0.332	- 2.680
			Cap	0.665	2.774
			ICT	-0.028	- 5.325
			Sigma-squared	0.157	10.360
			Gamma	0.136	6.389
			Log L		7.605E+07
			N of obs		181