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THE ECONOMIC EFFECTS OF INFORMATION TECHNOLOGY: FIRM LEVEL EVIDENCE FROM THE ITALIAN CASE

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Abstract
Employing a large data set of manufacturing firms the paper tries to assess the impact of information and communication technology (ICT) on productivity growth in Italy and to investigate the differences in ICT adoption between North and South of the country. Not all firms invest in ICT and skills, or better to say, not at the same rate. This situation is found to be at the base of the broad productivity variance across the sample. In Italy performance asymmetry has a strong territorial identity since in the North firms invest more in ICT and ICT complements relatively to the South which appears to be rather backwards. A standard regression methodology is employed to calculate the growth rate of productivity and the impact of ICT adoption on it. We then focus on the different matching between human capital and ICT adoption in the two areas. Our findings support the idea that using ICT has beneficial effects on overall productivity growth. Moreover, the use of ICT can help firms in the South to catch up relatively the northern ones, provided that they employ more skilled workers.

JEL: D24, L23, O30

Keywords: Factor complementarities, Firm organisation, Human capital, Information and communication technologies, New economy.

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Introduction

Modern production is progressively more characterised by technology and information, consequence of high technology firm development and the diffusion of new knowledge and processes. What we observe in advanced economic systems is a progressive structural change towards highly innovative sectors such as electronics, informatics and electric equipment. At the same time innovations spread across traditional productions, which partly benefit from this new trend. From this perspective, growth is the output of continuous invention and use of technology. New products, new processes and new organisational form can shift upward the production function and increase output. New technologies strengthen the base of highly innovating firms, which enhance their set of eligible choices and gain many benefits in term of performance. At the same time new sophisticated opportunities may end up delaying the performance of remaining more traditional sectors.

Information technology represents a very special form of embodied technological change which does not necessarily completely identify with capital deepening. Even if there is an embodied technical change as new ICT equipment are introduced in many other sectors, the use of ICT capital can boost the diffusion of knowledge ameliorating the system possibility frontier, generating disembodied technical change.

The rapidly growing use of ICT assets, termed new economy to emphasize inflation-free growth, has a wide determining role in explaining sustained productivity improvements. One of the very features of this new functioning of the economic systems is the growing importance of network externalities, which are generally associated with ICT production and use. Though the quantification or direction of these externalities is still rather uncertain, the massive use of ICT realised in the second half of the 1990s suggests that a considerable amount of disembodied technological change may have spread across many sectors. Trade is greatly benefiting from better real-time information and product distribution. Communication and co-operation is quicker and less costly. Opportunity to enlarge the business interest area is simpler, so is integration and devolution of new and old tasks, both within and without the individual firm.

The importance of ICT in production practices reflects an unprecedent decrease in the relative price of computers. It has been estimated that over the most recent years quality-adjusted prices of computer hardware have been declining at around 28% during the period 1995-99. Several causes can be identified for such a dramatic fall; progress in microchips, fibre-optic cables, satellite, memory chips, semiconductors and processors. This continuously ameliorates the price performance ratio of ICT capital goods with a consequent reduction in user cost relatively to other form of capital and stimulates a consistent substitution process in labour and traditional production inputs. In this respect, ICT has become progressively more important for output growth and labour productivity. Although the consensus does not appear to be unanimous and some outstanding questions still remain, from the beginning of 1990 s several firm level analyses find evidence that ICT has important effects on firm s productivity levels. Its use allows several benefits in terms of costs and time saving, embracing organisation, routines, information, quality and variety of output (Brynjolfsson and Hitt, 2000).

The possibility of new world-wide technologies does not necessarily mean automatic performance improvements. As Solow (1960) points out, improvements in technology influence production only when they can carried into practice through appropriate capital formation or through the replacement of old processes with the latest ones. Such implementation is certainly not free, instead it is costly and investment specific. A well defined set of technological purpose oriented activities need to be started.

In explaining productivity ICT represents only a small component of a complex set of causalities, such as the whole system of complementarities (skill, infrastructure, organisation, diffusion, adoption, adaptation, etc.) which embrace both tangible and intangible aspects. Moreover, the returns to ICT investment are strictly dependent on the changing organisational practises (the *fixed effect*). In this respect a crucial role is played by managerial and worker capabilities. ICT is part of a complex framework where each single component lies, in the most various forms, on the already available system, with which it interacts through multifaceted pyramidal relations. There cannot exist the top without building the rest. If such mutual influencing complementarities (complete cluster of associate complements in the words of Bresnahan *et al*., 1999) do not improve together many ICT benefits may be lost. This strongly suggests that such complementarities make ICT effective only in particular circumstances without which ICT turns mainly into higher cost rather than output improvements.

Though ICT has the power to reduce costs of co-ordination, communication, information and reorganisation it is a very costly process. ICT is tacit and firm specific in many aspects, making its transfer and use particularly uncertain. In order to take full advantage of ICT several instruments are needed to decodify information. In the end, it is the effort carried out by individual firms that determines successful ICT investment. Intangible assets such as development of new software, data base and quality skills involve important investment decisions.

According to Brynjolfsson and Yang (1997) for every 1$ spent on ICT capital a representative firm has to face additional costs of around 9-10$ in other complementary assets in order to make ICT work. With such order of magnitude it may be the case that full complementarities are financially precluded to many firms, which may not access ICT or do it only partially. There might be the case of structural organisational adjustment at firm level following ICT access decisions. The higher the level of ICT the more decentralised the firm. This in turn implies a reduction in vertical interaction and in firm size. These changes are a long time decision that will strongly characterise the firm s pace of economic evolution. What we observe in many OECD countries is that investment in the various forms of intangibles overcomes that in physical equipment. This latter is related to the technological receptivity of the system, which in turn is strongly defined by the level of organisation, human capabilities, and transmissibility.

ICT depends on skill-biased technical change and implies substitution of unskilled labour with equipment. Changes in organisation and service-quality services also require skills. We would expect that firms adopting high levels of ICT have more educated workers and better complements and, consequently, to show higher productivity. Moreover, this implies a relatively important learning lag that has to be fulfilled.

In principle the economic effects of ICT would appear far larger than it would by simply considering the amount of investment realised in a particular industry. ICT generates a flow of free benefits substantially larger than their own direct returns. Its contribution to economic growth spreads across sectors, industries and countries, giving rise to a considerable amount of complementary investments and innovations. The interplay and feed backs which strongly characterise the technological path gives rise various kind of spillovers, from the very use of the new capital to human resource reallocation across firms or practices. Total aggregate effect improves, making the whole system more efficient since given combinations of factors become more productive without augmenting the capital stock. Observing and distinguishing all this from a traditional regression is certainly not straightforward.

Starting from the TFP framework, this paper provides an attempt to assess the impact of ICT investment on output growth in a sample of Italian firms during the period 1995-1997. Is there any relationship between ICT investment and productivity and which factors may have influence? Can the ICT impact be ascribed to ICT investment only or it is more likely the case that also complements and skill differences do matter in the whole story? The question we also try to tackle is about the Italian structural duality.

The Schumpeterian suggestion according to which the overall system efficiency depends on the capability agents have to take advantage from a larger menu of available opportunities and to access superior technologies, supplies a useful start for interpreting North-South differences in Italy. This capability might well be one of the causes explaining ICT investment asymmetries among firms and the wide variance of performance observable throughout the sample. In Italy such diversity has a strong territorial identity since in the North firms invest more in ICT and ICT complements relatively to the South.

Estimation of productivity changes is quite a hard task. Several factors interfere in such exercise, heterogeneity of single firm characteristics and performances above all. Indeed a serious problem arises in estimating our function, a problem remained unsolved throughout this work: we are unable to distinguish between the various types of capital. Another important limit of this study lies on the data calculations, which could only be carried out for the period 1995-97. Given the short time horizon of our sample (the only one available to our knowledge) quantifying changes in trend productivity growth is, in fact, precluded too. This also constraints us catching dynamic and cyclical effects. Case study evidence strongly suggests significant dynamic effects of ICT, reinforcing the idea of organisational rearrangements, adjustment and absorption lags. It is quite likely that present investment is correlated with past investment. Production may affect productivity and *vice versa* (through learning, diffusion, production spillovers, lower and quicker information costs) leading to important concerns about cyclicality. However, we reasonably believe that this does not compromise our general purposes and that the main findings of the paper are likely to be valid even with such warnings.

The paper begins with a brief introduction on the role of information technology in the process of economic growth. In the first section the base theoretical framework underlying the production function and the total factor productivity is highlighted. Section 2 outlines the methodology employed. Section 3 contains a description of data set. Section 4 provides the main econometric findings. Finally some conclusions are drawn.

1. Growth accounting and total factor productivity: the underlying theory

The production function framework represents a well-established starting point in explaining connections among various types of relevant factors and production.

$Y_i\,(t) = A_t\; f_i\,(K_i\,(t), L_i\,(t))$ i= 1 n (1.1)

Where Y_i stands for output, K_i and L_i for capital and labour respectively and A_t is the level of technology.

Differentiation and rearrangement allows this equation to be transformed into a growth rate version:

$$\frac{dY}{dt}/Y = \frac{dA}{dt}/A + a\frac{dK}{dt}/K + b\frac{dL}{dt}/L \qquad (1.2)$$

where *dY* is the natural logarithm of added value growth, *dK* is the log of capital change and *dL* the log of labour force growth. a and b are the output elasticity of capital and labour respectively.

Equation (1.2) simply states that weighted growth of output equals weighted growth of inputs plus the rate of disembodied technical change that depends solely on time.

The rate of TFP change comes then straightforward:

$$\frac{dA}{dt}/A = \frac{dY}{dt}/Y - a\frac{dK}{dt}/K + b\frac{dL}{dt}/L \qquad (1.3)$$

term A_t can be regarded as an index of TFP to the extent that productivity is estimated from the value-added concept of output. With constant return to scale and competitive market, TFP gives us a measure of how efficiently inputs are transformed into final products. As suggested by Solow (1960) computation of TFP requires then real market values of the variables under the hypothesis of perfect foresight. Typically, social marginal products can be measured by observed factor prices. If it is not the case measure biases are likely to occur. Moreover, the condition $a + b=1$ needs to be satisfied if all output variation is attributed to the two factors employed.

One straightforward way of measuring the growth rate of TFP is by computing A_t at each date using time-series data on the variables. Once obtained the labour and capital growth rates, adjusted by weighting their shares in total production value, they are subtracted from output growth rate. The remaining residual is the TFP growth rate. However, this would imply aggregating respective shares of each input payment in total output (i.e. social factor marginal products equal to observable factor prices). This clearly has costs in terms of heterogeneity.

An alternative procedure to compute TFP is the regression approach, which has the advantage that there is no need to know factor shares in advance since they are directly computed from the regression through the coefficients. This latter carries on the usual econometric application issues such as omitted variables, measurement errors and simultaneity, particularly if we easily admit the possibility of K and L non exogenous with respect to A_t. Errors in the correct contribution of capital and labour are to be expected (Griliches, 1995).

These two approaches do not consider the effects coming from other variables making the interpretation of the residual quite ambiguous. TFP is composed by a myriad of factors that are not easy to disentangle. Even if TFP is generally viewed as a proxy for technical progress, its improvements are not only consequences of ICT investment (embodied R&D) but also of other unmeasured forces (disembodied technical change) such as organisation, efficiency, scale economies, mark-up pricing, output reallocation, increasing return to scale, learning, spillovers, etc.. Moreover, investment-specific technical change (or unmeasured intangible investments) such as adjustment costs for installation, complementary investments, training costs, new business design incentive systems also play a determining role in the overall efficiency of the system.

Interpreting TFP calls then for a number of cautions, particularly if we consider that intangible assets are generally accounted for current expenditures rather than proper investment. Thus, mismeasurement of capital, in particular omission of intangible investment may affect (and indeed it does) TFP. This directly drives one to the question of aggregation and production shares.

As Barro (1998) points out, if we measure capital as loss of consumption and K_1, K_2 have the same costs, then aggregation will not vary in consequence of changes in capital composition. Since in equilibrium capital productivity is the same any reallocation does not affect TFP. No change will be registered. However, if K_1 becomes more productive there will be a reallocation towards this input, which will not be caught by the regression, consumption cost has in fact, not changed. To make such variation operational in the regression, *K* should be measured in terms of real acquisition prices.[1]

Another problem stems from the very use of capital which is not necessarily fully used or at least its use may follow trend or cycles. As Gordon (2000) underlines, there might well the case of firms investing heavily in capital without employing it fully. In such a case the growth accounting would register an increase in inputs, would search for any increase in production, which in fact does not occur. As consequence computed TFP would appear smaller than the actual one.

Adjustment for labour and capital may help explaining a greater share of TFP.[2] In estimating the production function *K* and *L*

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[1] Jorgenson (1963, 1966), developed aggregate capital input measures accounting for assets heterogeneity applying asset-specific user costs as weights to aggregate across services from the different types of assets. If user costs reflect marginal productivity, changes in aggregate capital input come from two distinct sources: changes in the quantity of a given assest and changes in the composition of the various types of assets with different marginal products and user costs.

[2] Since assessing numerically different impacts from ICT, spillovers and capital deepening is greatly complicated, labour productivity can be used as measure of productivity. In this way it is possible to catch the final result of these mutual interacting effects on just one variable without distinguishing between traditional capital deepening, embodied technical change and productivity spillovers (Stiroh, 2001). If capital deepening grows less than labour productivity for instance, there would be unidentifiable spillovers (though one could use the difference as proxy).

Given $LP = Y/L$, expressed in productivity growth rather than levels it becomes $lp=y-l$, where lp can be divided into K/L growth (capital deepening) ought to be desegregated among types and qualities (Jorgenson and Griliches, 1967). The variable labour is in fact a vector of various kinds of workers who are strongly characterised by age, gender, education and skills. We need weights to aggregate heterogeneous workers to get a less crude approximation for its measure.[3] As result productivity would be more represented. The same story applies to capital.

Considering input desegregation by quality groups Jorgenson and Griliches (1967) and Jorgenson *et al.* (1987) found that indifferentially measured TFP growth overstates true TFP growth if the composition of inputs is improving over time.[4] The same conclusion is reached by Bassanini et al. (2000). Neglecting or failing quality aspects or improvements in labour or capital leads to overstating the Solow residual. There would be a change in productivity, which is not registered by the regression.

To conclude this section it might be worth mentioning that the endogenous growth theory provides new insights for interpreting TFP by considering R&D and a human variable as explanatory factors. In this perspective, residual has to be interpreted in the light of increasing returns (in R&D particularly), spillovers, purpose aimed R&D efforts (but also public policies and other

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and TFP growth. We then need a proper production function to have K and L marginal contribution and TFP. The final effect actually depends on their relative importance and degree of change: if K is not very important it implies that L and TFP growth should bee very close. If instead, K is important and K/L is not fixed, L productivity and TFP growth do not necessarily move together.

[3] Considering the changes in hours worked rather than merely accounting for variations in the number of workers for instance, depicts reality a bit more accurately, particularly if one considers the moving trend of hours worked during time.

[4] When inputs are perfectly measured by quality adjustments TFP only picks up disembodied improvements (Oliner and Sichel, 2000).

factors).[5] Mansfield (1965), Griliches (1973, 1979) Nelson-Winter (1982) Romer (1990), Aghion-Howitt (1998), suggest that R&D can be a fair explanatory variable of TFP. In this case the residual reflects both, an exogenous component (*à la* Solow) and an endogenous one.

Since R&D greatly affects TFP a more accurate procedure should account for such effect. Barro (1998) suggests to clean the output growth accounting for R&D effects:

$$\frac{\dot{A}}{A} = \frac{\dot{Y}}{Y} - r_K \frac{\dot{K}}{K} - w_L \frac{\dot{L}}{L} - (1-a).\frac{(current\,R\,\&\,D\;\;flow)}{(market\,value\,of\;\;past\;R\,\&\,D)} \quad (1.4)$$

Moreover, it is strongly stressed, again, that in the specific circumstance of technological inputs the effects are not only on production and labour productivity but it is very likely the case of indirect effects to TFP (Schreyer, 2000). Following Lucas (1988) and Romer (1986) such externalities, together with the rate of technical change, are both captured by TFP estimates, which should be in this form:

$$\frac{\overset{*}{\dot{A}}}{A} = \frac{\dot{A}}{A} + r_K \frac{\dot{K}}{K} q \quad (1.5)$$

Where star stands for actual value and q represents the spillover effects deriving from capital which improve total output growth.

2. Methodology

The first step consists in estimating the unexplained residual employing a production function approach.[6] This has the big

[5] Among the factors explaining TFP, Black and Lynch (2000) found that workplace practice account for about 90 per cent of TFP in the US manufacturing.

[6] This procedure differs from Antonelli (1997) were residuals are non-explained factors after controlling for the constant term, which in fact, proxies TFP.

advantage of allowing OLS estimation.[7] The notion of ICT investment is the usual one and includes computer hardware, computer software and telecommunications equipment. However, data are not endowed with ICT capital stock nor can they distinguish firms that do not use ICT capital or firms that simply employ old ICT[8]. Methodological concerns about the capital measurement are not addressed here. We are aware that this may imply loosing some degree of heterogeneity at firm level, partly due to the adoption of ICT capital and to other differences (organisational structures and human capital, for instance). While constraining for estimating single factor elasticities, such procedure is still reasonable to check if firms show different impacts of ICT on firms productivity. Given the capital stock measurement complexity, we believe that simplicity is a good reason for doing so. Our main targets are in fact not directly dependent on this[9].

We then focus on the procedure to derive the rate of growth of TFP. Total factor productivity is a function of the level of all types of capital employed (physical and human) and other forces affecting productivity:

$$TFP = f\,(K, H, O) \qquad (2.1)$$

[7] For a discussion see Morrison (1999), Greenwood *et al.* (1997). For a dual approach to TFP calculation in the Italian industries see Atella and Quintieri (1998).

[8] Employing the same data set, Bugamelli and Pagano (2001) estimate the ICT capital stock with the perpetual inventory method.

[9] An alternative to simplicity would be a dual approach which allows to overcome the three unrealistic hypotheses of the growth accounting: perfect competition, absence of scale economies and short-run fixities. Atella and Quintieri (1998) compare a traditional Solow residual with the fully adjusted one, finding that the role of technical progress is greatly reduced. They conclude that a major role in the correction of Solow residual is played by scale economies. This approach is precluded to us by data deficiencies on inputs and output prices.

Following Griliches (1973) we consider a Cobb-Douglas where an exponential trend has been included to approximate the other forces affecting productivity:

$$Y_{i,t} = Kict_{i,t}^{b}\ Koth_{i,t}^{a}\ H_{i,t}^{\ 1-a}\ A_i\, e^{lt} \qquad (2.2)$$

where Y , *Kict*, *Koth* and H stand respectively for output, ICT, other capital and human capital-augmented labour, while the subscripts refer to the *i-th* firm and time. The parameter A is constant and *ë* is the rate of disembodied external technical change.

As previously stressed the level of human capital plays an important role on productivity growth. Including it in the estimation should allow us to capture some firm heterogeneity. Assuming each unit of labour (L_i) trained with E_i years of schooling the human capital-augmented labour can be expressed as $H_i = e^{f(E_i)} L_i$, where $f(E)$ represents the efficiency of a unit of labour with E years of schooling relative to one with no schooling.[10]

Differentiating with respect to time, equation (2.2) can be expressed in terms of total factor productivity:

$$y = b\ k_{ICT} + a\ k_{OTH} + (1-a)h + l \qquad (2.3)$$

$$y - a\ k_{OTH} - (1-a)h = l + b\ k_{ICT} = tfp \qquad (2.4)$$

where lower case letters represent rates of growth.

Given that the rate of growth of ICT capital stock is not available for the firm s sample and because of the difficulties in constructing a reliable measure of ICT capital stock (i.e. employing the perpetual inventory method with hedonic prices), we can rewrite equation (4.2) in an alternative way. Considering that:

$$b = \frac{\partial Y}{\partial K_{ICT}} \cdot \frac{K_{ICT}}{Y} \quad \text{and} \qquad (2.5)$$

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[10] If $f(E) = 0$ for all E we obtain a standard production function with undifferentiated labour (Hall and Jones, 1999).

$$b\ k_{ICT} = \frac{\partial Y}{\partial K_{ICT}} \cdot \frac{K_{ICT}}{Y} \cdot \frac{\dot{K}_{ICT}}{K_{ICT}} = \frac{\partial Y}{\partial K_{ICT}} \frac{\dot{K}_{ICT}}{Y} \qquad (2.6)$$

where dots represent variable variations.

Assuming that $\dot{K}_{ICT} = I_{ICT}$, equation (2.6) becomes:

$$tfp = l + h\ k_{ICT} = l + r\ \frac{I_{ICT}}{Y} \qquad (2.7)$$

where r is the rate of return to ICT investment, or the marginal product of K_{ICT}, while I_{ICT}/Y is the net investment in ICT as ratio to total output.

Equation 2.7 has quite convenient features. It allows to calculate the marginal product of the stock of ICT capital without a measure of its level.

3. The data set

In the empirical analysis we employ data from the Survey of Manufacturing Firms (SMF) by Mediocredito Centrale which contains information on about 5000 firms with more than 11 employees. All Italian firms with more than 500 employees are included in the sample and balance sheet data are also available. From 1989 Mediocredito Centrale issued three releases of the survey each covering a triennium (1989-91, 1992-94 and 1995-97). Only the last survey contains information about investment spending ICT.

From the last release we end up with a sample of 1481 firms over a period of three years. The sample has been further divided into two groups: firms located in the North (1191) and in the Centre-South (290) (South in the following).

Table 1 reports descriptive statistics for the main variables. The average firm workforce is around 180 employees for nearly 18 billion lire of value added (VA). The ICT investment ratio (ICT over total investment) is 10%, average output growth is around 7% and increment of ICT investment is some 3.5% for the whole period. Comparison between North and South gives us some interesting base lines. In the latter, firm size is smaller both considering value added or number of employees. Firms in the South show a lower level of ICT investment and ICT investment over VA, a higher level of human capital and of capital output ratio. Firms in the South experience a greater increment of labour costs and reduce of about 12% the labour force. This latter value is similar in the rest of the country. However, ICT investment ratio is nearly the same in the two groups (around 10%). Four issues deserve particular attention.

1) SMF does not report data on the stock of ICT capital, only the three-year level of ICT investment is displayed. Lacking data on the stock of ICT capital, its life, obsolescence and hedonic prices the attempt to calculate marginal productivity with the traditional production function might be misleading.

2) There is a considerable number of firms that do not invest in ICT over the period 1995-97 and most of these firms belong to the Southern regions. A correct estimation of ICT adoption would be crucial to understand the determinants of firm investment behaviour.

3) Splitting the sample according to the level of ICT investment and considering high ICT investors[11] allows to directly identify some differences between the two geographical areas. The gap is now wider. ICT investment ratio is larger among the firms in the South (17%), while labour force increases of some 45%. This latter is nearly 60% in the North. Increments of labour force lead to a 10% increase of labour costs in the South and 7% in the North. It seams that these firms are filling the technological gap with respect to northern counterparts.

4) In the South firms employ more skilled workers, with an average human capital of 3.2, compared with 2.7 in the North.[12] This latter issue will be further discussed in section 5.

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[11] Subsample above the median value of the distribution.

[12] Human capital is measured by the number of years of schooling above compulsory school attained by each worker. See Appendix.

4. Empirical results

Our aim here to verify the impact of ICT on total factor productivity growth. The procedure in section 2 is then employed to check whether ICT adoption produces different effects according to firm geographical location.

Productivity growth is estimated from the following equation:

$$y_{i,t} = b_1 k_{i,t} + b_2 h_{i,t} + e_{i,t} \quad (4.1)$$

where *y* is the growth rate of value added, *k* is the growth rate of the physical capital minus the 1995-97 level of ICT investment, *h* represents the growth rate of human capital augmented labour and e is the error term.[13] All is expressed as log differences. Although the known caveats, the regression approach allows us to avoid the difficulties related to the calculation of the human capital factor share.[14] Panel estimation of equation (4.1) provides quite satisfactory results:

$$y_{i,1995-97} = 0.060 k_{i,1995-97} + 0.461 h_{i,1995-97} + e_{i,1995-97} \quad (4.2)$$

Wght.$R^2 = 0.99$; (all significant at 1% level)

The distribution of the residuals across firms can be considered a proxy for the distribution of growth not accounted by the two production factors. Hence, they can be viewed as depending from the increase in the general efficiency of the production process over the period.[15]

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[13] For variable description and the estimation method see the Appendix.

[14] In Hall and Jones (1999) this problem is surmounted using capital output ratio instead.

[15] Alternatively this measure can be obtained from a production function with a fixed effect model, adjusting for *N* cross-sectional intercepts (one for each firm in the panel), and employing the resulting vector as a measure of TFP. Moreover, allowing the intercept term A_i to vary at firm level (i.e. for exogenous reasons some firms are more efficient than others) would prevent from overstating the contribution of ICT wherever ICT investment is linked to unmeasured characteristics yielding to omitted variables problems (Brynjolfson and Hitt, 1995).

The average growth of TFP is about 1.1%, northern firms (1020 obs.) show a 0.76% and southern 2.6% (245 obs.).

In order to check relationship between increases in the firm s efficiency and ICT investment we estimate equation (2.7):

$$e_{i,1995-97} = l + r \frac{I_{ICT,1995-97}}{Y_{i,1995-97}} + m_{i,1995-97} \qquad (4.3)$$

where $\varepsilon_{i,1995\text{-}97}$ is the residual of equation (4.2), I_{ICT}/Y is the ratio of ICT investment to value added and m the residual. GLS estimation gives:

$$e_{i,1995-97} = 0.003 + 0.81\, I_{ICT}/Y \qquad (4.4)$$

Wght.$R^2 = 0.97$; (all significant at 1% level)

As previously said $\tilde{n}$ can be interpreted as the marginal product (rate of return) of the new ICT capital installed in the period. It implies putting one additional euro of ICT capital into service yields roughly Euro 0.40 of output per annum. Considering that a reasonable estimate of ICT rental price is about 0.35 (Brynjolfsson and Hitt, 1995), investing in ICT still gives a net positive benefit. However, this estimate is subject to some degree of uncertainty since total ICT investment has been employed rather than its net value, which is not available in the data set.

Given the average value of I_{ICT}/Y (0.015) and of the marginal product of ICT capital, its contribution to output growth is straightforward, resulting to more than 1 percentage point (0.81 0.015 = 0.012) over the two periods.[16]

The next concern is to see whether this result changes when we separately consider the two areas of the country. Running equation (3.4) for the North it gives:

$$e_{i,1995-97} = -0.008 + 1.549\, I_{ICT}/Y \qquad (4.5)$$

[16] The same contribution is 0.35% per year for the period 1996-99 and 0.28% per year for the period 1991-95 in Daveri (2001). Schreyer (2000) finds 0.21 per annum during the period 1990-96. It should be noticed, however, that in this latter work only hardware ICT capital is considered, as the author himself underlines, neglecting software ICT implies consistent underestimation of this coefficient.

Wght.R^2 = 0.95; (all significant at 1% level)
For the South we get:

$$e_{i,1995-97} = 0.049 - 2.074 I_{ICT} / Y \qquad (4.6)$$

Wght.R^2 = 0.38; (all significant at 1% level)
Interestingly, while marginal product is positive for the North, firms in the South show a negative effect of ICT investment on productivity. Contrarily to the most general expectations this would imply negative benefit associated with ICT investment in the South.
Differences in the two areas are even reinforced from the top of Table 2. While in the North output growth is below the average and ICT/VA ratio is above the average, in the South the opposite situation realises, along with a consistent lower level of ICT investment. However, the estimation capture the average firm and does not necessarily apply to the whole sub-sample. We then need to go one step deeper and see what actually happens within the group when differentiating by some specific firm characteristics.
Determinants of productivity are indeed many and complex and not always observable from the survey, current ICT capital stock among the others. Differences between the two areas may be attributed to increases in the level of external efficiency as well as to increments in firm s ICT use ability.[17] Our attention is driven towards ICT investment and human capital levels and the way their combination (matching) may affect ICT marginal productivity. Next section will try to shed some light into this very issue.

4.1 The matching hypothesis

Concerning the relation between human capital and ICT investment the theory is very clear and offers several well-

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[17] Internal efficiency in the use of ICT capital depends mainly on allocative efficiency, on the choice of ICT investment intensity to achieve maximum technical efficiency and maximum scale efficiency (Lee and Barua, 1999).

established roles. If ICT and human capital are somehow complements, we would expect firms realising higher combinations to be more efficient relative to its competitors. However, the matching and its relation with growth are far from being unambiguous. As Bresnahan *et al.* (2001) underline, if potential complementarities were entirely understood, maximising behaviours were always respected and no lags or adjustment costs existed, then ICT and labour demand would tell us all we need about such mutual relations. It clearly is a mere theoretical wish.

As long as firms are not using a maximising well-matched combination, a standard production function can be used to identify complementarities and to see how various combination sets influence productivity. Given that different combinations of factors lead to different productivity performances, the robustness of the matching hypothesis can be tested straight away. Following Bresnahan *et al.* (2001), we construct a set of four mutually exclusive dummies according to the level of ICT investment and of human capital and we let them interact in a loglinear regression. This function has the advantage of being simple and of straightforward interpretation. The regression is then[18]:

$$\ln(Y) = a + b_1 \ln(K) + b_2 \ln(L) + g_1 D_{HICT,HH} + \\ + g_2 D_{HICT,LH} + g_3 D_{LICT,HH} \qquad (4.1.1)$$

where Y is output, K is the stock of capital and L represents labour cost. Variables D are dummies. Since the intercept term has been introduced, the low ICT-low human capital dummy has been omitted for obvious multicollinearity reasons. The coefficients represent the average product for each group and are to be

[18] A dummy for workplace organisation would be highly desirable, unfortunately our sample would be dramatically reduced after controlling for it. The South would be particularly affected preventing us to carry out inter-area comparisons.

interpreted as the percentage difference from the $D_{LICT,LH}$ group mean[19].

Results show a relatively strong evidence in support of the complementarity argument (see Table 2). While there is a little difference between firms with no matching and the coefficients are relatively small whatever the combination, average productivity dramatically increases for firms adopting high levels of both ICT and human capital (more than twice). High levels of ICT are most efficient when combined with high skills. However, the matching does not find support in the case of low ICT and low human capital firms, either considering the whole sample or the two groups.

Running the regression on the two geographical areas some interesting facts come out. In the North values are similar to those in the general case (due probably to its weight in terms of number of firms) and suggest that adopting low ICT and high human capital is more efficient than in the reverse case. Among firms in the South the matching hypothesis appears to be even reinforced. Firms with appropriate matching between human capital and ICT are far more productive (+53%) than the group average which, remember from regression (4.6), show a substantial negative ICT productivity. The gap between the two remaining combinations appears to be less important.

So far still average type considerations have been pursued while decisions are usually taken on marginal bases. Bottom of table 2 may help us to close part of the puzzle. Looking at the high ITC and high human capital firms it can be seen that, though less dynamic in terms of VA growth and endowed with a lower ratio of ICT/VA, firms in the South show a notable greater ICT marginal contribution with respect to the northern counterpart (2.44 *versus* 0.92) and completely reverse the value obtained for the whole sub-

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[19] Excluding the LICT,LH group the regression normalises with respect to it. Moreover, since differences between the intercept term and the single average product group are log differences, they express percentage changes.

sample. This has a strong corollary since, contrarily to what previously reported, it now suggests that when the matching applies investing in ICT in the South is even more productive than in the North.

5. Concluding remarks

In this work we try to investigate the impact ICT has on total factor productivity and its contribution on output growth. Based on firm-level data our main empirical finding is that such impact is positive and relevant. Given the great economic and structural disparities keeping the North and the South of the country consistently different, our concern is also to see whether this main conclusion still applies at gross regional level. The answer here seams to be negative. In the most efficient North ICT productivity and its contribution to growth is far greater than in the rest of the country where average ICT contribution is of about the same amount but of negative sign. From this perspective the South seams to pay for its structural weakness and backwardness with respect to the North.

However, this might give a misleading picture if we do not differentiate within the two areas for any appropriate firm characteristic. In fact, when firms grouped according to the way they combine ICT investment and human capital results look quite different. In this case, the average firm adopting the most efficient cluster of combination behaves notably differently from the remaining ones. Results are even stronger when the two areas are considered separately. They now show that highly endowed firms in the South perform a better productivity not only with respect to their group but also to those with similar endowments in the North, suggesting important returns on ICT investment provided that these firms employ more skilled workers.

Some facts push us to take the values we obtained cautiously. Series are in fact in nominal term. Deflationated they could give slightly greater coefficients though the main results are not likely to be affected. Secondly, differences in marginal productivity between North and South may well be due to existing levels of ICT capital stock and consequently to different positions in the productivity curve. Not less important the role played by the sectors single firms belong to. Because of sample restrictions all these points could not be considered here. Finally, the matching argument may appear weaker if we consider that the measure of human capital employed reflects schooling accomplishments and not necessarily true skills in the use of technologies. Further research is strongly encouraged on these very issues.

References

AGHION, P. and P. HOWITT (1998), *Endogenous Growth Theory*, Cambridge, Mass.: The MIT Press.

ANTONELLI, C. (1997), New Information Technology and the Knowledge-Based Economy. The Italian Evidence, *Review of Industrial Organization*, **12**, 593-607.

ATELLA, V. and B. QUINTIERI (1998), Productivity Growth and the Effects of Recessions, *Giornale degli Economisti e Annali di Economia*, Vol. 57, **3-4**, 359-386.

BARRO, R.J. (1998), Notes on Growth Accounting, *NBER Working Paper* No. 6654, Cambridge, MA.

BASSANINI, A., S. SCARPETTA and I. VISCO (2000), Knowledge, Technology and Growth: Recent Evidence from OECD Countries, *National Bank of Belgium, Working Paper* No. 6.

BRESNAHAN, T., E. BRYNJOLFSSON and HITT L. (1999), Information technology, workplace organization, and the demand for skilled labour: firm level evidence, *NBER Working Paper* No. 7136 (May).

BRYNJOLFSSON, E. and L. M. HITT (1995), Information Technology as a factor of Production: The Role of Differences Among Firms, *Economics of Innovation and New Technology*, **3** (4 (Special Issue on Information Technology and Productivity Paradox)),183-200.

BRYNJOLFSSON, E. and L. M. HITT (2000), Beyond Computation: Information Technology, Organizational Transformation and Business Performance, *Journal of Economic Perspectives*, Vol. 14, **4** (Fall), 23-48.

BRYNJOLFSSON, E and S. YANG (1997), The Intangible Costs and Benefits of Computer Investments, *Proceedings of the International Conference on Information System*s, 1997, Atlanta, Georgia (December).

BUGAMELLI, M. and P. PAGANO (2001), Barriers to Investment in ICT, Banca d Italia, Temi di discussione, No. 420 (October).

DAVERI, F. (2001), Information Technology and Growth in Europe, Università Bocconi, IGIER, Working Paper No. 168 (June).

GORDON, R. J. (2000), Does the New Economy Measure up to the Great Inventions of the Past?, *Journal of Economic Perspectives*, Vol. 14, **4** (Fall), 49-74.

GREENWOOD, J., Z. HERCOWITZ and P. KRUSELL (1997), Long-Run Implications of Investment Specific Technological Change, *American Economic Review*, Vol. 87, **3**, 342-362.

GRILICHES, Z. (1973), Research Expenditure and Growth Accounting, in B. R. Williams eds.*, Science and Technology in Economic Growth*. New York: Macmillan, 59-83.

GRILICHES, Z. (1979), Issues in Assessing the Contribution of Research and Development Productivity Growth, *Bell Journal of Economics*, Vol.10, **1** (Spring), 92-116.

GRILICHES, Z. (1995), R&D and Productivity: Econometric Results and Measurement Issues in P. Stoneman ed., *Handbook of the Economics of Innovation and Technological Change*, Oxford Blackwell.

HALL, R. E. and C.I. JONES (1999), Why Do Some Countries Produce So Much More Output per Worker than Others?, *Quarterly Journal of Economics*, Vol. 114, **1**, 83-116.

JORGENSON, D.W. (1963), Capital Theory and Investment Behaviour, *American Economic Review*, Vol. 53, **2** (May), 52-89.

JORGENSON, D.W. (1966), The Embodiment Hypothesis, *Journal of Political Economy*; Vol. 74, **1**, 1-17.

JORGENSON, D.W., F. M. GOLLOP and B. M. FRAUMENI, (1987), *Productivity and U.S. Economic Growth*, Cambridge MA, Harvard University Press.

JORGENSON, D.W. and Z. GRILICHES (1967), The Explanation of Productivity Change , *Review of Economic Studies*, Vol. 34, **3** (July), 249-83.

LEE B., A. BARUA, (1999), An integrated Assessment of Productivity and Efficiency Impacts of Information Technology Investment: Old Data, New Analysis and Evidence, *Journal of Productivity Analysis*, **12**, 21-43.

LUCAS, R. E., Jr. (1988), On the Mechanics of Development, *Journal of Monetary Economics*, Vol. 22, **1**, 3-42.

MANSFIELD, E. (1965), Rates of Return from Industrial R&D, *American Economic Review Papers and Proceedings*, Vol. 55, **2** (May), 310-322.

MORRISON, C.J. (1999), *Cost Structure and the Measurement of Economic Performance*, Norwell, MA: Kluwer Ac.

NELSON, R.R., and S.G. WINTER (1982), *An Evolutionary Theory of Economic Change*, Cambridge, MA: The Belknap Press of Harvard University Press.

OLINER, S.D. and D.E. SICHEL (2000), The Resurgence of Growth in the late 1990s: Is Information Technology the Story?, *Journal of Economic Perspectives*, Vol. 14, **4**, 3-22.

ROMER, P. M. (1986), Increasing Returns and Long Run Growth, *Journal of Political Economy*, Vol. 94 **5**, 1002-37.

ROMER, P.M. (1990), Endogenous Technological Change, *Journal of Political Economy*, Vol. 98, **5**, (Supplement), 71-102.

SCHREYER, P. (2000), The Contribution of Information and Communication Technology on Output Growth: a Study of the G7 Countries, *OECD STI Working Paper*, No. 2.

SOLOW, R.M. (1960), Investment and Technical Progress, in K. Arrow *et al.* eds., *Mathematical Methods in the Social Sciences,* Stanford: Stanford University Press, 89-104.

STIROH, K. J. (2001), Information Technology and the U.S. Productivity Revival: What do the Industry Data Say?, *Federal Reserve Bank of New York*, *Staff Report*, No. 115.

Appendix

Variables calculation

K: capital stock at book value (net of depreciation). From this level the whole period ICT investment has been subtracted.

Y: value added

N: number of employees

H: human capital-augmented labour. *H*= *N E*, where E is an index constant over the period and represent schooling attainment as differences from compulsory attainment.

$$E = \frac{compulsory + 5 \cdot high\ school + 9\ degree}{workforce}$$

where *compulsory*, *high school*, and *degree* represent respectively the number of employees with compulsory, school leaving and degree attainment.

I_{ICT}:ICT investment. SMF reports one value of total investment in hardware, software and telecommunications for the whole period.

I_{ICT} / *Y:* total ICT investment is divided to the average value added.

Rates of growth

Rate of growth are obtained as log differences.

$y = log\ (Y_{1997})\text{-}log\ (Y_{1995})$

$k = log\ (K_{1997})\text{-}log\ (K_{1995})$

$h = [log\ (N_{1997})\quad log\ (N_{1995})\ ]\quad log\ (E)$

Dummies

$D_{HIT,HH}$: represents a dummy for firms above median level of ICT investment and above median level of human capital. Accordingly:

$D_{HIT,LH}$: high ICT investment, low human capital;

$D_{LIT,HH}$: low ICT, high human capital;

$D_{LIT,LH}$: low ICT, low human capital.

Estimation method

Estimates of equations (4.2), (4.4), (4.5) and (4.6) are obtained from a panel of 1481 firms over the periods 1995-96 and 1996-97 with a maximum number of 4443 observations. Given that residuals are heteroskedastic and uncorrelated, a pooled weighted regression is employed, with the GLS method. The estimated variances are obtained by a first-stage pooled OLS regression. Estimated coefficient values and covariance matrix are given by the standard GLS estimator. For further details about estimation method see the Technical Notes in Eviews 3.1 manual.

Tables

Table 1: **Descriptive statistics Whole sample, North, South and matching firms - Average values 1995-1997.**

	Value Added (mill. IT £)	Fixed capital (mill. IT £)	Labour costs (mill. IT £)	# of employees	ICT investment (mill. IT £)	Ratio of ICT investment to total investment	Human capital	Capital output ratio	Capital stock % change	Labour costs % change	Employees % change
Whole sample											
Mean	17908.5	19060.3	10869.7	179.8	202.0	0.104	2.7	1.2	13.6	8.4	3.1
Observations	4427	4427	4427	4427	4270	3936	4427	4427	3798	4005	4426
North											
Mean	19309.8	20182.3	11690.8	190.0	224.2	0.106	2.6	1.14	14.1	7.5	6.7
Observations	3560	3560	3560	3560	3418	3230	3560	3560	3103	3227	3559
South											
Mean	12154.5	14453.3	7498.1	138.1	112.6	0.095	2.9	1.8	11.5	12.3	-11.7
Observations	867	867	867	867	852	706	867	867	695	778	867
Matching of High level of Human capital and high ICT Investment * North											
Mean	30212.3	30677.9	18323.2	288.3	405.2	0.148	2.7	1.08	9.9	7.7	59
Observations	1876	1876	1876	1876	1876	1876	1876	1876	1719	1770	1875
Matching of High level of Human capital and high ICT Investment South											
Mean	23467.8	25377.4	14210.5	248.04	334.6	0.174	3.2	1.6	12.4	10.2	46
Observations	281	281	281	281	281	281	281	281	236	257	281

***** By high level of Human capital is meant a value above the median. High level of ICT is any level above 400 millions of liras.

Table 2: **Marginal product of ITC Whole sample, North, South and matching firms**

	VA % Change	ICT investment / VA %	ñ(MP of ICT capital)
Whole sample			
Mean	5.1	1.5	0.81
# of firms	1469	1481	1259
North			
Mean	4.6	1.7	1.54
# of firms	1185	1191	1014
South			
Mean	7.5	0.8	-2.07
# of firms	284	290	245
Matching of High level of Human capital and high ICT Investment*			
North			
Mean	8.6	6.0	0.92
# of firms	197	198	197
Matching of High level of Human capital and high ICT Investment			
South			
Mean	5.1	3.3	2.44
# of firms	26	26	26

***** By high level of Human capital is meant a value above the median. High level of ICT is any level above 400 millions of liras.

Table 3: **Average product by grouping according to the level of ICT investment and human capital**

ICT investment / Human capital	High	Low
High	0.28	0.10
Low	0.13	-

Table 4: **Average product by grouping according to the level of ICT investment and human capital - North**

Human capital \ ICT investment	High	Low
High	0.21	0.13
Low	0.09	-

Table 5: **Average product by grouping according to the level of ICT investment and humancapital South**

Human capital \ ICT investment	High	Low
High	0.53	0.14
Low	0.13	-