ICT, R&D and Productivity Growth: Evidence from Italian Manufacturing Firms

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Abstract

Despite the large body of firm-level analyses devoted to the impact of technological capital on productivity, a robust evidence for countries other than US is still needed. Early studies focused on R&D, while most recently technological capital has been measured also by means of ICT-related variables. In this paper, starting from a traditional production function framework, we examine the technological capital-productivity relationship using both R&D and ICT intensity measures. By employing the Capitalia survey's data for a longitudinal sample of 1119 Italian and a larger sample of 3918 manufacturing firms, firm-level regressions are carried out for the TFP growth over the period 1998-2000.

Controlling for industry effects, firm size and other variables, we found that both R&D and ICT intensities on value added exert a positive impact on TFP changes. However, the intensity of ICT is significant only when inserted with a lag; in this case, moreover, the estimated rate of return is higher than that of R&D. Thus, concerning ICT investment, the results are consistent with the "delay hypothesis", calling for the need of further and complementary outlays in intangible assets and organisational changes.

Our findings legitimate a moderate optimism. Since both R&D and ICT investments are found rewarding at the micro level, there is room for policy interventions aimed at increasing the technological capital of Italian firms which is still behind that recorded in other developed economies.

Keywords: R&D; ICT; productivity growth.

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1. Introduction

A raising body of empirical studies at firm-level emphasises the role of technological or "knowledge" capital in the explanation of productivity growth. Early studies focused on R&D investment and found in most countries a robust evidence for its significant contribution to productivity growth, especially in the cross-sectional dimension. Most recently, technological capital has been also measured by means of ICT-related variables, but the evidence is not as robust as in the previous case (especially for countries other than the US).

In this paper, starting from a traditional production function framework, we examine the technological capital-productivity relationship by taking into account both R&D and ICT intensity measures. Using the Capitalia data-set, firm-level regressions for TFP growth are carried out with a longitudinal sample of 1119 Italian manufacturing firms over the period 1998-2000. The same model is also tested with a larger sample composed of 3918 firms.

Controlling for sector specific effects, firm size and other variables, we found that both R&D and ICT intensities on value added exert a positive and significant impact on TFP changes. However, the intensity of ICT is significant only when inserted with a lag; in this case, moreover, the estimated rate of return is higher than that of R&D. Thus, concerning ICT investment, the above results support the "delay hypothesis": the efficiency gains from ICT show up with some lags and this is probably due to the need of further and complementary organisational changes and investments in intangible assets.

Despite the well-known technological weakness of the Italian industrial system, especially in terms of R&D, our findings legitimate a moderate optimism. Since the investments in R&D and ICT are found rewarding at micro level, there is room for policy interventions aimed at up-grading the technological capital of Italian firms.

The paper is organised as follows. Section 2 reviews the theoretical framework and provides a selected survey of the large literature on technological capital and productivity at the firm level, distinguishing between early (R&D-based) and recent (ICT-based) contributions. Section 3 presents some descriptive statistics of the R&D and ICT activities in Italian manufacturing, placing them in the national and international context. Section 4 is devoted to the regression analysis. Section 5 discusses the policy implications of our findings as well as the main research direction to which our study needs to be extended.

2. The R&D and ICT contributions to productivity growth

2.1 Theoretical framework

Seminal contributions on the R&D/productivity relationship at firm-level[1] focused on the production function approach (so-called primary approach[2]); usually, a Cobb-Douglas function relates firm value added[3] not only to labour and physical capital inputs but also to a measure of "technological" or "knowledge" capital proxied by the cumulative investment in R&D. Then, by assuming constant returns to scale with respect to traditional inputs and output elasticities equal to their shares on valued added (as in a perfectly competitive market) an index of Total Factor Productivity can be obtained. Finally, by time-differencing the log-linear version of the original production function, the equation for TFP changes can be expressed as follows:

$$\frac{\dot{TFP}_i}{TFP_i} = \lambda + \alpha \frac{\dot{KRD}_i}{KRD_i} \qquad [1]$$

Here, the subscript i refers to firms, λ denotes an exogenous rate of efficiency growth common to all firms, while the coefficient α can be viewed as the excess in the output elasticity with respect to R&D capital. In effect, micro-data bases do not usually provide the accurate disaggregation of labour and capital inputs needed to separate out the R&D inputs. In this case, the only solution for addressing the double counting problem is that of considering the "normal" R&D output elasticity as already incorporated in the traditional inputs' coefficients.

In order to take into account, along with that of R&D, the contribution of Information and Communication Technologies on productivity growth, a variable for changes in the ICT capital can be added to the right-hand side of equation [1], yielding:

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[1] See the surveys of Mairesse and Sassenou (1991), Griliches (1995), Bartelsman and Doms (2000) and Mairesse and Monhen (2003).

[2] Another (smaller) stream of literature – i.e. the dual approach – is based on cost functions.

[3] If we consider gross output (like turnover), we need to add also materials and energy among the inputs. However, these inputs are like to present a more pronounced bias of endogeneity, being more sensitive to the short term adjustments to output shocks. For this reason, when it is available, most contributions prefer to use a measure of the net output (value added), as we do.

$$\frac{\dot{TFP}_i}{TFP_i} = \lambda + \alpha \frac{\dot{KRD}_i}{KRD_i} + \beta \frac{\dot{KICT}_i}{KICT_i} \qquad [2]$$

Obviously, being the ICT capital computed as the cumulative investment in hardware, software and communication equipment, the double counting issue arises again and, as a consequence, the coefficient β in [2] must be interpreted as the excess output elasticity with respect to ICT capital (its normal or theoretical value being incorporated in the coefficient of "total" capital – including ICT items - used for computing the TFP index).

Due to the unavailability of longitudinal R&D and ICT data for a sufficiently long period of time, capital variables are difficult to compute. For this reason, one can use a version of equation [2] where the technological factor features as investment intensity. This version is derived as follows. Avoiding from now on the inclusion of subscripts *i*, the elasticities α and β times the rates of change of R&D and ICT capital can be expressed as

$$\alpha \frac{\dot{KRD}}{KRD} = \frac{\partial VA}{\partial KRD} \frac{KRD}{VA} \frac{\dot{KRD}}{KRD}; \qquad \beta \frac{\dot{KICT}}{KICT} = \frac{\partial VA}{\partial KICT} \frac{KICT}{VA} \frac{\dot{KICT}}{KICT}$$

where *VA* stands for value added. Denoting the rate of return of R&D as $\rho = \partial VA/\partial KRD$ and that of ICT as $\sigma = \partial VA/\partial KICT$, and simplifying, lead us to rewrite the two identities as:

$$\alpha \frac{\dot{KRD}}{KRD} = \rho \frac{\dot{KRD}}{VA}; \qquad \beta \frac{\dot{KICT}}{KICT} = \sigma \frac{\dot{KICT}}{VA}$$

By taking the R&D and ICT investments (in a given year or period) as proxies for the R&D and ICT capital variations,[4] the "intensity version " of equation [2] will be:

$$\frac{\dot{TFP}}{TFP} = \lambda + \rho \frac{R\&D}{VA} + \sigma \frac{ICT}{VA} \qquad [3]$$

[4] This implies to assume a negligible depreciation rate for the R&D capital stock, close to zero, as suggested by Griliches and Lichtenberg (1984).

Again, for the reasons explained above, the estimated coefficients ρ and σ in [3] should be interpreted as "excess returns" with respect to R&D and ICT investments.

2.2 A brief survey of the evidence

While a number of empirical contributions on the relationship between R&D and productivity are available across countries and industries, firm-level studies are less numerous and this is maimly due to the lack of micro-data. The US account for the vast majority of them and for most of the other OECD countries some evidence has been provided only since the early-Nineties. Among European countries, Italy is a case in point for the shortage of micro-data on R&D expenditures, especially if one neglects some studies based on small (and, thus, not fully representative) samples.

Despite theoretical frameworks seem to have reached a stage of maturity, empirical constraints have determined a wide range of findings regarding the R&D impact on productivity[5]. Surveys of the literature (see, for instance, Mairesse and Mohnen, 2003) show that, while the estimated output elasticities range from 5 to 30%, the rates of returns (gross of depreciation) vary between 10 to 80%. However, as showed by the comparative estimates performed by Mairesse and Hall (1995) and Harhoff (1998), the two different ranges of variation are mainly attributable to the types of data and estimation methods: ceteris paribus, cross-sectional estimates are higher (and statistically more significant) than those based on time-series.

A notorious example of the cross-sectional studies including an R&D capital variable was provided by Griliches (1980), who used a sample of 883 US manufacturing firms for 1963 and, controlling for industry dummies, found a significant output elasticity with respect to technological or knowledge capital equal to 7%. Since then, this approach has been followed by numerous scholars (cf. Mairesse and Sassenou, 1991), and all the studies confirm that R&D capital is a statistically significant explanatory factor of the productivity differences between firms. Obviously, the main shortcoming of cross-sectional studies is that they cannot account for firm (time-invariant) heterogeneity.

Time-series studies are relatively younger; their increasing number in recent years is

[5] The estimated contribution of R&D to productivity varies widely according to data-bases (cross-section versus longitudinal data), model specifications and econometric techniques. The choice of the latter has been often limited by data constraints and only a few studies have been able to use different specifications and econometric methods on the same sample (see Hall and Mairesse, 1995; Haroff, 1998).

due to both a wider availability of longitudinal data and the advancements of panel data econometrics. The early contributions are based on the "within" estimation, sometimes coupled with the time-series "growth rate" specification[6]. During the last decade, instead, there has been a surge of GMM-based works or non-OLS techniques (see Crepon et al. 1998, Lööf and Heshmati, 2002) which often specify a larger simultaneous system of equations including, along with that for productivity, an innovation production function.

On overall, these dynamic specifications, being based on the "within-firm" variability, present the advantage of separating out the impact of firm-specific effects on performance, but are not immune from other biases; in particular, as summarised by Mairesse and Mohnen (2003), they need a sound specification of the dynamic evolution of the variables, in comparison to a cross-sectional test, where static long-term relationships between inputs and performance are estimated. More generally, the problem of finding an appropriate specification for lags is particularly binding for knowledge and organisational variables, as when we go to estimate the effects of ICT investment (see below). In theory, either for R&D and ICT investment, the most comprehensive time-series framework is offered by a GMM-based framework, but this choice is often prevented by the unavailability of sufficiently long time-series for both original variables and instruments.

Representative contributions of the time-series approach include Hall and Mairesse (1995) and Harhoff (1998). Hall and Mairesse consider a sample of 197 French firms providing data from 1980 to 1987. Within a Cobb-Douglas framework, the dependent variable is value added per worker, regressed over the usual inputs and (different versions of) the R&D capital stock. The R&D elasticity is significant and larger in the cross-sectional dimension, while its time-series equivalent (be it "within", long-differenced or first-differenced) is smaller and often statistically insignificant. In terms of rates of return, two times-series specifications are compared: first-difference and long-difference, with the R&D coefficient significant only in the first case.

Harhoff works with a sample of 443 German firms over the period 1979-89, presenting, beside the usual cross-sections, also times-series estimates, with the R&D coefficient expressed both as elasticity and rate of return. The typical cross-sectional findings are confirmed (highly significant coefficients for the R&D capital stock, up to 14%), and also the results for the time-series specifications are significant (although the elasticity of R&D

[6] In the "within" estimation the yearly data ($x_{i\,t}$) are re-calculated as differences from their firm-means (x_i). In the "growth rate" estimation, instead, the first differences of the variables in logarithms are taken.

capital is smaller in size). With respect to the rates of return, the R&D intensity coefficients are always significant and stable across specifications (i.e. both in terms of gross and net rates of return and with different time lags).

Due to the lack of micro-data, the number of similar studies for Italian firms is not high although has increased in recent years thanks to the same survey on Italian manufacturing firms that we shall use in this paper. A recent example is that of Medda et al. (2004), who employ the survey results for the periods 1992-94 and 1995-97. For each period (concerned, respectively, with a sample of 2268 and 2215 firms), the authors estimate a two-year difference equation of TFP changes regressed on a measure of R&D intensity over turnover (rather than value added as in equation [3]). Moreover, the likely R&D selection bias (due to a significant portion of the sampled firms that did not report R&D expenditures) is taken into account by means of a Heckman-like procedure. They found significant rates of returns of R&D investment equal to 29% for the period 1992-94 and 36% for 1995-97.

Another recent study for Italy that also use the last wave of the same survey (1998-2000) – as we shall do in section 4 – is that of Aiello and Cardamone (2004). Starting from a standard equation in which labour productivity is explained by the ratios of traditional and R&D capital over labour input, the authors add a proxy for R&D spillovers and exploit the time dimension of the survey by using annual data from 1994 to 2000 for a panel of 1017 manufacturing firms. With GLS estimates in first differences they found a significant elasticity of R&D capital (slightly above 5%) while GMM estimates provide a higher but less significant parameter; in both cases the coefficient of the spillovers' variable is positive and significant.

After the initial scepticism lead by the well-known "Solow paradox", in the last years there has been a mounting evidence in favour of a positive impact of ICT on economic and productivity growth. Although either at the aggregate level and across industries the findings remain far from being conclusive, in selected countries and sectors (in particular the US and some tertiary industries) the most recent works point towards the existence of a robust positive relationship between ICT production/usage and productivity growth. See Jorgenson et al. (2002) for the US; O'Mahony and van Ark (2003) for the EU countries; for a cross-country perspective see Pilat and Wölfl (2004).

The findings are less equivocal at the micro-level of analysis, and particularly encouraging since the validation of the ICT-productivity relation seems to be confirmed by several methodologies and with different ICT indicators, including qualitative ones (see the review provided by Pilat, 2004). Indeed, this is a recent achievement, since the empirical evidence available during the Nineties was often counter-intuitive (a negative o neutral effect of ICT on productivity) and, on overall, not robust (cf. Brynjolfsson and Yang, 1996). At that time, the shortage of statistics on ICT adoption or investment was binding also for the US since the few available data sets were provided by private sources and based on small (i.e. non representative) samples of large firms (such as Compustat, Fortune1000, Forbes 400).

It should be stressed that the very nature of the ICT variable can matter for the significance of its impact on productivity: while in the previous decades a measure like the number of PCs per employee could have provided a good proxy of the intra-firm diffusion of ICT (see Lehr and Lichtenberg, 1999), this is going to become more and more questionable in recent years[7]. A fuller account of the digital revolution should include not only computers and software, but also related communication equipment, whose incidence has been growing since the end of the Nineties. For these reasons, data on ICT outlays are probably the best and less ambiguous measure of the "true" ICT usage within firms.

Among the most recent firm-level works using a production function approach, Lehr and Lichtenberg (1999) study a matched sample of US non agricultural firms over the period 1977-93. The main descriptive evidence they uncover is a dramatic acceleration in the diffusion of computers (from mainframes to PCs) at the firm and establishment level. Moreover, this increase is recorded both in terms of qualitative indicators and investment or capital stock figures. The main specification, derived from a standard Cobb-Douglas framework, explains changes in value added by means of labour, traditional capital and Information Technology capital. The model is estimated in pooled times-series with both firm and industry specific effects and additional controls; the number of observations varies between 1487 and 10692, according to the data-set used. The estimated equation, besides the elasticities of traditional inputs, offers a test for the presence of an excess output elasticity to IT capital.

Among the results, the above test is significantly passed in the specification with industry-effects; moreover, even after introducing firm-specific effects, the "ICT share" coefficient remains significant, although smaller. Because of that, the authors also control for the presence of omitted variables, positively correlated with IT inputs and productivity growth, whose main example is the intensity of skilled labour. However, even the inclusion of labour quality proxies does not affect the IT coefficient estimates. Finally, also in the specification in which the IT share is expressed in terms of investment (rather than capital stock), a significant and positive coefficient emerges.

The first contribution which has directly investigated the ICT impact on TFP growth at micro-level is that of Brynjolfsson and Hitt (2003). The authors study a sample of 527 large US firms over 1987-1994 with various time-difference specifications. The basic framework is built on a standard Cobb Douglas production function, where value added is regressed over traditional inputs (labour and ordinary capital) and computer capital; then, a TFP index is derived and the estimated coefficients interpreted as elasticities. The main result of this work is that the size of the contribution of computerisation to productivity growth, which is positive and significant, varies according to the time-lag analysed. In fact, while in the short term (1-year difference) they find normal returns to computer capital[8], over a longer period (5- to 7-years lags) these returns are up to five times greater. The authors do not dispose of organisational change variables, so that a proper test of their influence is prevented. However, the previous evidence on the changing impact of 'strict' computerisation suggests that the super-normal output elasticiy to computerisation is due to complementary investments in training, effective deployment of new technologies and related organisational changes, whose lengthy implementation also explains the time-lag.

Combining the evidence gathered both for R&D and ICT investment, it seems that a specification with more than one-year lag is necessary in order to account for the delay in which their effects on performance will show up. Further, this choice, beside being a more realistic approximation of the "true" dynamic process, makes the estimated coefficients less influenced by the short-term adjustments of the firms' inputs mix.

Again, for Italy (as well as for other European countries) micro data on ICT investment are still in short supply. The only truly longitudinal firm-level data-set is that drawn from the Survey on Firms Accounts (see the next section), but its micro data are not released to external researchers. Milana and Zeli (2004) have (exceptionally) obtained them to perform a firm-level analysis on the causes of the purported TFP slow-down of Italy in the last decade. After having constructed the technological (best-practice) frontier of production at industry level by means of a DEA technique, the authors build a Malmquist-like index of

[7] Lucchetti and Sterlacchini (2004) observe that within a sample of SMEs located in Central Italy the mere presence of PCs, e-mail facilities and Internet access is not adequate to discriminate between firms and introduce more accurate indicators of ICT usage.

TFP growth for each firm[9]. Then, they estimated, separately for each industry, a firm-level regression for TFP changes expressed as long differences over the period 1996-99. The latter are explained by the intensities of R&D and ICT capital stock on total capital, together with the wage share of skilled workers on total labour costs; moreover, controls for size, location and other firm characteristics are used. Among their results, the coefficient of ICT capital intensity is positive and significant for most industries, the skill factor is of smaller significance (and only for a few industries), while the R&D intensity is never significant: in sum, the firms which over the years invested more in ICT (and hence built a greater share of ICT capital) had an higher TFP performance.

With the exception of this study, for Italy is not possible to reconstruct a reliable indicator of ICT capital stock at firm-level. Consequently, the only alternative is that of using an intensity measure of ICT investment. We shall return on the above as well as other specification issues in section 4, devoted to our estimate of the R&D and ICT impact on the TFP changes of Italian manufacturing firms. The next section presents a descriptive analysis of the recent trends of ICT and R&D investment in Italy with particular reference to manufacturing industries.

3. ICT and R&D intensities in Italian manufacturing

In line with EU countries, Italy records a lag in the ICT diffusion with respect to the US. Recent data (see table 1) show that, on average, over the period 1997-2000 the Italian overall ICT investment intensity (both on value added and total non residential investment) is very close to the EU average. However, by looking at the ICT composition, the Italian performance is markedly divergent from the EU-15, with a higher intensity of communication equipment (in line with that of the US) and, by definition, a lower share of hardware equipment and software.

Although surprising, the Italian lead in communication investment is a rather consolidated evidence. First, it dates back to the mid-Eighties, when the digital revolution was still far to come. Already at the beginning of the Nineties, the Italian share was higher than the EU average and during that decade remained at the same level of the US one. Because of that,

[8] In other words, in the short-run the estimated contribution of computers is equivalent to their cost, with no effect on productivity growth

this high investment intensity cannot be simply related to the notorious Italian "mobile phones" boom, which is a more recent phenomenon. The figures for the period 1985-95 should partly reflect the huge investment in public-telephony infrastructure carried out by the former Telecom incumbent, which engaged itself in the coverage of the country with traditional (copper wire) lines.

Table 1 - ICT investment intensity in the US, UE and Italy: 1997-2000 (current prices)[10]

	US	EU-15	Italy
ICT/GDP	4.43	2.54	2.39
Communication Equipment/GDP	1.17	0.68	1.13
ICT/Total Non Residential Investment	28.29	16.92	16.44
Communication Equip./Total Non Resid. Investment	7.46	4.53	7.66

Source: Timmer et al. (2003).

The presence of this pervasive country-wide infrastructure and the eventual liberalisation of TLC in the EU (1998) have been the premise for the subsequent wave of investment of the second half of the Nineties, devoted to the digitalisation of the existing fixed line infrastructure (mainly via ISDN and XDSL technologies), the build-up of the mobile line infrastructure and, on the user-side, the investment in terminal equipment and related networking infrastructure. The sustained level of communication investment in recent years, depicted in table 1, is largely due to the increasing efforts of communication-using firms, which has compensated the contemporaneous reduction of investments in the public switched telephony network[11]. As indicated by some business statistics (e.g. EITO 2000; p. 393), since 1997 in Italy there has been a noticeable surge of the share of the ICT market attributable to two components directly related to connectivity and networking. First, concerning IT hardware, the growth rate of "data communication hardware" (including LAN and switching/routing equipment) over 1997-2000 was two or three times higher than that of

[9] Technically, the Malmquist index of productivity used by the authors builds on the concept of distance functions. The output distance function, which is a measure of technical efficiency, expresses the proportional expansion of output for a given level of inputs.

[10] For international comparisons, the use of ratios in current rather than constant values is preferable, due to the experimental nature of hedonic price indexes for ICT; these are built on methodologies which are still fluid and different across countries. For a similar choice, see Daveri (2003) and De Arcangelis et al. (2004).

computer hardware. The same happened for end-user equipment (including mobile phones sets) and network equipment (transmission, circuit switching equipment and cellular radio infrastructure), whose positive dynamic surpassed even the positive trend of the aggregate "carrier services" (including call charges)[12]. To summarise, the high share of communication equipment in Italy has recently been driven by adopting firms and is far from being confined to the purchase of mobile phones.

For ICT investment data at industry level, we look at the two available data sources for Italy: the Survey on Firms' Account (SFA) carried out by Istat (the Italian Statistical Office) and the Capitalia survey. Although the ICT data are provided only for the last part of the 1990s and micro data are not publicly available, the SFA presents the advantage of being a fairly good representation of the entire economy: because of its large sample and accurate methodology[13] we can infer that it better registers also the "true" ICT investment intensity of Italian manufacturing industries. However, the SFA does not contain the richer set of information provided by the Capitalia survey which, on the other hand, refers only to manufacturing firms. The latter is based on a rotating panel and provides both a comprehensive sample (we call it ALL) and a longitudinal smaller panel (LONG). The first sample covers a larger number of firms for a three-year period (respectively 1995-97 and 1998-2000 in the last two available waves), while the second sample is much smaller, being composed of those firms which are present across different waves.

In this section, we focus on the LONG sample, which will be our reference sample for the regression analysis. In fact, together with the other considerations explained in section 4, its higher relevance lays on the fact that its figures, although not coincident, are quite close to those provided by the SFA which, as already said, should be considered as the most reliable statistical source.

Preliminarily, a few methodological remarks. The intensity of ICT investment is computed at constant (1995) prices by using the ICT investment deflators provided for Italy

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[11] In fact, concerning the communication-producing firms, the privatisation of the national TLC incumbent (formerly SIP, later Telecom Italia) was followed by a dramatic slow-down of its investment in public infrastructure.

[12] This was not the case of other EU countries, where some components of the "network equipment" aggregate experienced a marked decrease and, as a whole, the growth was lower than that of the "carrier service" aggregate (EITO 2000; p. 401).

[13] With the exception of some tertiary sectors, it covers the entire Italian economy. With reference to its 1997 edition, the SFA survey covers, for the firms with less than 20 workers, a stratified sample of the universe, while for those with 20 workers and more it covers the entire Italian population. The SFA's results are adjusted for missing answers and re-proportioned to the universe (see ISTAT, 2001).

by Timmer et al. (2003).[14] Moreover, since the Capitalia survey provides ICT investment data broken down by item – hardware, software and communication equipment – in order to obtain the aggregate "ICT investment at constant prices" we did not use the aggregate deflator but those referring to each item, weighted by the actual Capitalia composition: in this way the different weights of ICT items across Italian manufacturing industries (and firms) are taken into account.

Further, it must be pointed out that, contrary to the ICT variable, the R&D intensity refers to nominal data. In fact R&D-specific deflators are not available, and the most suitable deflator for R&D should be that of value added; but this implies that nominal and real R&D intensities on value added would coincide.

Table 2 - ICT investment intensity in Italian manufacturing

	Survey on Firms' Accounts	Capitalia LONG sample
ICT/Value Added 1995-97 (current prices)	n.a.	0.99
ICT/Value Added 1998-2000 (current prices)	0.66	0.75
ICT/Value Added 1995-97 (1995 prices)	n.a.	1.28
ICT/Value Added 1998-2000 (1995 prices)	0.90	1.13
ICT/Tot. Investment 1995-97 (current prices)	n.a.	6.46
ICT/ Tot. Investment 1998-2000 (current prices)	3.33	3.46
ICT/ Tot. Investment 1995-97 (1995 prices)	n.a.	8.44
ICT/ Tot. Investment 1998-2000 (1995 prices)	4.62	5.36

Sources: our computations from SFA and Capitalia surveys. Value added and total investment deflators are taken from ISTAT (*National Accounts*). ICT investment deflators are taken from Timmer et al. (2003).

Table 2 shows that, on overall, the figures of the Capitalia LONG sample are higher than those of SFA, both for the intensities over value added and total investment. Moreover, within the Capitalia survey, the data show a decline of the ICT intensity on total investment from 1995-97 to 1998-2000, in real terms. This decrease should not be necessarily interpreted in a negative fashion. In fact, a distinguishing character of the ICT investment is the non-persistence: firms do not necessarily carry out a constant flow of investment over contiguous

[14]The implicit deflator for ICT investment is taken from the *GGCD Total Economy Growth Accounting Database*. The implicit deflator is a harmonised price index obtained following the method proposed by Schreyer (2002). Assuming a global model of relative prices between ICT and non-ICT goods, it is built on the US hedonic prices, adjusted for the difference in general inflation. A three-year average has been taken in order to smoothen fluctuations in the series (see Timmer et al. 2003).

years, but rather adopt discontinuous modules of hardware, software and telecom equipment, in bounces. For instance, a firm may introduce a new server in one year, and later implement new communication applications or software up-grading: in other words, as the potential of new ICT solutions unfold gradually, so do the adoption decisions of the firms. Obviously, these diachronic patterns of investment are more likely to be captured by close samples - as is the LONG one - since the evidence for open samples is more affected by the different behaviour of the new firms that entered, the old that exited and the old that remained.

In the following tables, the data arising from the LONG sample in the last two waves of the Capitalia survey are compared across firm sizes and manufacturing industries. Table 3 shows that, from 1995-1997 to 1998-2000, on average, there has been a small decline in both the R&D and ICT intensity on value added. The two phenomena are quite similar. In fact, the R&D decline affects only the two biggest classes; the ICT decline affects the smallest one and, again, the two biggest classes. However, their interpretation differs. While for non persistent technological outlays (as ICT) a temporary decrease of intensity should not be necessarily emphasised as a bad new, the decline of the R&D activities legitimises a more pessimistic interpretation. In particular, our findings confirm that in the last part of the Nineties there has been a worrying decline in the technological level of the largest Italian firms (Sterlacchini, 2004).

Table 3 - R&D and ICT intensity in Italian manufacturing by firm size (LONG sample)

Size class (workers)	Number of observations	R&D/Value Added		ICT/Value Added	
		1995-97	**1998-2000**	**1995-97**	**1998-2000**
11-20	228	1.39	2.29	1.48	1.20
21-50	486	1.62	1.68	1.10	1.54
51-250	293	1.55	2.15	1.23	1.56
251-500	66	2.96	2.11	1.61	1.45
Over 500	46	2.59	2.27	1.20	0.70
TOTAL	1119	2.29	2.15	1.28	1.13

Sources: our computations from Capitalia survey. R&D intensity: current values. ICT intensity: real values (for the deflators see table 2).

Table 4 illustrates the distribution of R&D and ICT intensity across manufacturing industries. On overall, the average manufacturing trend in the R&D and ICT investment intensities hides a high variability among industries which should be ascribed to the different technological opportunities. A minority portion of this variability can be attributable to the use of value added as the weighting indicator, while some anomalous intensity values that arise for a few industries are probably due to the small number of observations.

However, several expected regularities emerge. R&D intensity is confirmed to be higher in high-tech industries: Office machinery, Electronics, Chemicals and pharmaceuticals. Other medium and low-tech industries record R&D intensities higher than those expected. For some traditional consumer good industries this could be due to an over identification of R&D activities by responding firms,[15] while for other industries (such as Rubber and plastics and Mechanical engineering) the rise of the R&D intensity is likely to be a real phenomenon.

Table 4 - R&D and ICT intensity in Italian manufacturing by industry (LONG sample)

Industries	n. obs.	R&D/Value Added		ICT/Value Added	
		1995-97	**1998-2000**	**1995-97**	**1998-2000**
Food, drink & tobacco	100	0.72	0.75	1.33	0.98
Textiles	126	1.85	1.45	0.90	0.88
Clothing	26	0.54	1.37	1.17	1.84
Leather & footwear	40	1.12	1.36	0.81	0.44
Wood & products of wood	46	0.43	0.74	1.24	0.87
Pulp, paper & paper products	37	0.23	0.58	0.90	0.64
Printing & publishing	35	0.37	0.05	3.43	2.20
Chemicals & pharmaceuticals	36	5.14	3.39	1.72	1.07
Rubber & plastics	73	0.87	3.24	1.20	1.22
Non-metallic mineral products	63	1.07	0.83	0.96	0.38
Basic metals & alloys	34	1.38	0.18	0.50	0.11
Fabricated metal products	150	0.77	0.88	1.37	0.75
Mechanical engineering (non electrical)	173	4.38	4.64	1.67	1.77
Office machinery, electrical engines, machinery & apparatus	42	1.29	4.93	0.81	1.52
Electronic apparatus, Radio-TV & Communic. Equipment, medical & precision instruments	37	4.98	3.37	1.65	2.04
All transport vehicles and equipment	37	3.12	1.63	1.10	0.88
Furniture, miscell. manufacturing, recycling	64	1.34	2.30	1.28	2.76
TOTAL	1119	2.29	2.15	1.28	1.13

Sources: see Table 3.

As far as the ICT intensity is concerned, the inter-industry comparison highlights that most ICT producers (present within the Office machinery and the Electronics-radio-TV aggregates) have an above-average ICT intensity, but they are far from being really "big ICT spenders" as they are expected to be. In effect, a major adopter is the Printing and publishing

[15] Within the Italian clothing and footwear industries, big "end of filière" manufactures perform high expenditures in design, pre-production developments and IPR protection and could have included them in the R&D aggregate.

industry which, as it is widely known, has been characterised by an ICT deepening process; moreover, also the Mechanical engineering registers an above average ICT intensity.

As a further regularity, we notice that - with a few exceptions - most of the R&D-intensive industries are at the top of the ranking for ICT intensity.

Table 5 - ICT investment destination in Italian manufacturing by industry: percentages on total investment (LONG sample)

	Hardware/ICT		Software/ICT		Comm. Equip./ICT	
Industries	1995-97	1998-2000	1995-97	1998-2000	1995-97	1998-2000
Food, drink & tobacco	68.5	58.2	28.6	32.8	2.9	9.0
Textiles	64.8	54.8	29.8	33.0	5.3	12.2
Clothing	52.6	60.2	45.0	29.8	2.4	9.9
Leather & footwear	62.5	58.9	30.0	32.1	7.5	9.0
Wood & products of wood	58.6	57.5	36.3	35.2	5.1	7.3
Pulp, paper & paper products	67.1	56.3	32.0	33.2	1.0	10.4
Printing & publishing	73.1	62.4	19.2	22.4	7.7	15.2
Chemicals & pharmaceuticals	48.4	51.1	38.7	29.9	12.9	19.0
Rubber & plastics	58.9	58.5	34.2	31.5	6.8	10.0
Non-metallic mineral products	33.5	46.4	65.7	44.6	0.7	9.0
Basic metals & alloys	62.8	59.5	29.1	31.0	8.1	9.5
Fabricated metal products	62.8	59.4	32.8	32.5	4.5	8.1
Mechanical engineering (non electrical)	69.2	66.8	27.5	24.8	3.3	8.4
Office machinery, electrical engines, machinery & apparatus	76.3	62.9	20.3	29.6	3.4	7.5
Electronic apparatus, Radio-TV & Commun. Equipment, Medical & precision instruments	66.8	60.6	23.7	27.6	9.6	11.8
All transport vehicles and equipment	69.1	57.2	25.4	33.0	5.5	9.8
Furniture, miscell. Manufacturing; recycling	56.0	54.8	41.9	36.6	2.0	8.7
TOTAL	62.6	60.2	32.1	29.6	5.3	10.3

Sources: see Table 3.

The above picture is complemented by table 5, which explores the destination of the ICT investment. From the first to the second wave of the survey it emerges a shift in favour of communication equipment (whose share almost doubles) and a corresponding decrease of both the hardware and software shares of ICT investment. However, there are important differences across industries: in fact, the share of communication equipment increases and becomes particularly relevant in Chemicals and pharmaceuticals, Printing and publishing, Textiles and Electronics-radio-TV industries. As already mentioned, by comparing tables 4 and 5, it emerges that most industries with a decline in ICT intensity also show a strong increase in the communication share (for example, see the industries going from Leather to Chemicals, from Non-metallic to Fabricated products, or Food and Transport). This suggests that in our sample we do not have a substantial process of hardware or software deepening/replacement, but rather a complementary (although less relevant in absolute terms) investment in connectivity, via communication equipment. Due to the complementary nature of these ICT components, this also suggests that, for the firms in our sample, the bulk of the preliminary hardware investment could have been made in the first period.

As a final comment, it should be stressed that while the decrease in the share of hardware equipment is an almost generalised phenomenon, in some industries there has been a significant increase also in the software share.

4. Regression analysis

The regression analysis across Italian manufacturing firms is based on the following specification for the TFP variation (subscripts *i* for firms are omitted):

$$\Delta \ln TFP_{98\text{-}00} = \lambda + \rho\,(R\&D/VA)_{98} + \sigma\,(ICT/VA)_{98} + \delta \ln EMPL_{98} + \gamma\, SPINOFFS + \eta\, M\&A + \Sigma_j \lambda_j\, INDUSTRY_j + \varepsilon \qquad [4]$$

In a Cobb-Douglas framework and under the assumption of constant returns to scale in traditional inputs, the level (in logs) of TFP is computed as value added minus labour and capital inputs (always in logs), multiplied by their respective shares on value added. These shares (averaged over 1998-2000) do not refer to single firms bur are computed for each industry: this implies to assume that there are as many perfectly competitive markets as industries, each of them with a different capital/labour ratio. Nominal value added has been deflated by 1995 price indexes, available at industry level (mainly at 2-digit).[16] The value of gross fixed capital stock (including buildings) derives from balance sheets data and has been expressed at 1995 prices by using the deflator of the aggregate investment in Italian manufacturing. Finally, labour input is measured by the number of total workers.

In equation [4] the change in TFP is computed as a two-year difference in logs[17] between the initial and final year of the last wave of the Capitalia survey: 1998-2000. In

[16] However, for a restricted number of industries, more disaggregated deflators (up to 3-digit) are available from National Accounts. To exploit this wealth of information and to minimise deflation distortions, we used the highest disaggregated deflator available for each industry.

[17] The difference in logs is an approximation of the rate of change of TFP (see equation [2] in section 2.1) over the period considered.

principle, the analysis could have started before by using the previous wave of the survey (1995-97). However, we did not do so because, for the reasons that shall be explained later, both the use of longer differences and a panel data estimation with first-differences were not feasible solutions.

Moving to the right-hand side of equation [4], R&D investment is expressed as a share on value added (VA) and refers to the initial year of the survey wave: in this way R&D intensity is pre-determined with respect to the TFP variation. Thus, according to the discussion developed in section 2.1 (see in particular the passage from equation [2] to [3]), we employ the "intensity version" of the equation for TFP changes and the parameter ρ can be interpreted as an excess rate of return (gross of depreciation).

The same consideration applies to σ, the coefficient of ICT intensity on value added. However, contrary to R&D expenditures, the survey does not provide annual data on ICT investments: firms are asked to report only their cumulative expenditures on ICT items over the previous three years. As a consequence, that referring to the initial year (1998) is not the "true" ICT intensity but represents one third of the total investment in ICT during 1998-2000. Due to this imputation, the ICT intensity variable is not truly pre-determined with respect to TFP changes, and this aggravates the problem of endogeneity[18]. To alleviate the latter, we used the previous wave of the Capitalia survey (1995-97) from which we obtained a lagged variable for ICT intensity referring to the year 1997: again, since ICT investments were reported for the entire three-year period, we imputed to 1997 one third of the total investment. The lack of annual data for ICT investment prevented us from implementing a panel data estimation in first-differences or performing an estimation of equation [4] based on differences longer than two years: in effect, the only way to get a truly lagged ICT variable it to compute an index of TFP change over the last wave of the survey and to regress it on the ICT intensity resulting from the previous wave. Obviously, to do so we cannot use the entire (ALL) sample of the last wave, but are compelled to refer to the (LONG) sample of firms that took part in both waves (reducing dramatically the number of observations from 3918 to 1119).

The ICT intensity is expressed at constant (1995) prices by using the ICT investment deflators already described in the previous section. Here, it is sufficient to remind that ICT

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[18] Such a problem is not confined to the presence of contemporaneous explanatory variables. Even with lagged explanatory variables, the error term of equation [4] could be correlated to the intensities of R&D and ICT so that the endogeneity problem would remain unsolved. For a possible extension of our analysis, appropriate to address the above issue, see the concluding section.

investments at constant prices are not computed by using the aggregate deflator but those concerned with each ICT item: in this way, we take into account the different composition of ICT investment (hardware, software and communication equipment) across Italian manufacturing firms. It must also be reminded that, for the reasons already introduced in the previous section, the intensity of R&D on value added refers to nominal data.

The other explanatory variables included in equation [4] are used as controls. The natural log of total workers (lnEMPL) should capture the possible effect of firm size on TFP growth. Since our TFP index could have been affected by discontinuous changes in the size of firms, two other dummy variables are inserted in the regression: one for the spin-offs or the selling of plants or lines of business (SPINOFFS) and another for the mergers and acquisition (M&A) occurred during the period 1998-00. Finally, 16 industry dummies are included, with that for "Food, drink and tobacco" as the reference industry (for the complete list of industries see table 4 in the previous section).

Although we are aware of the possible biases, Table 6 presents the results of two OLS regressions carried out for equation [4] without lagging ICT intensities: the only advantage of doing so is the possibility of comparing the results arising from the LONG and the ALL sample, with the latter having a very large number of observations[19]. In effect, the findings are quite consistent between the two samples, suggesting that also the smaller one can be taken as representative of the whole manufacturing sector. The estimated (gross) rate of return of the R&D investment is significant in both samples; it is equal to 56% in the LONG and 44% in the ALL sample. The coefficient of the ICT investment, instead, is barely significant in both samples (the level of confidence is inferior to 95%), and its magnitude in the LONG sample is quite small, considering that the coefficient expresses a gross rate of return. Thus, in the specification without lags, there is not robust evidence that ICT investment is rewarding at micro level. Apart from a few industry effects, the coefficients of the other dummy variables are never significant.

Obviously, due to the fact that the ICT variables used are not pre-determined with respect to the growth of TFP, the above results should be treated with extreme caution. In fact, the picture is different when the ICT variable is lagged (that is referring to 1997, the last year of the previous survey's wave). In fact, the results of the OLS regressions for the LONG

[19] Preliminarily, the two samples underwent a consistent process of data cleaning. In particular, patent outliers for R&D and ICT intensities were excluded.

sample (reported in Table 7) show that the (gross) rate of return of the lagged ICT investment is significant and higher than that of R&D investment (79% versus 53%).

The latter results suggest that those of the previous regressions are probably influenced by the fact that ICT outlays are not necessarily persistent and, often, are undertaken in a modular way. A firm that invested a lot in the recent past does not need to do the same in the current period. In short, due to the non persistent and modular nature of ICT investment and according to the "delay hypothesis" (calling for the need of further and complementary outlays in intangible assets and organisational changes before the productivity gains from ICT show up), the most suitable specification for TFP changes is that with the lagged ICT intensity.

Moreover, along with the basic specification of equation [4], we also carried out separate regressions including, as explanatory variables, the intensity of the investment in hardware equipment (HWICT/VA), software (SWICT/VA) and communication equipment (COMMICT/VA). The correlation between the three variables (and especially between hardware and software investment) prevented us from putting all of them in the same regression. Moreover, and most importantly, the obvious need of investing in each of the three ICT items (possibly not in the same period of time) does not allow us to interpret their coefficients as rates of returns. As a consequence, we do not consider the values of the estimated parameters but only their level of statistical significance.

Our findings indicate that only the intensity of communication investment is significant at a 0.05 level of confidence; the coefficient of hardware investment is barely significant while that of software is not. Thus, the firms which invested substantially in communication equipment before the remarkable and generalised increase of outlays devoted to connectivity (see Table 5 in the previous section) have proved to be the most productive ones.

Table 6 - Determinants of TFP log differences 1998-2000: specification with non lagged ICT intensity

	LONG SAMPLE (1119 obs.)	**ALL SAMPLE (3918 obs.)**
Constant	-0.078	-0.048
$(R\&D/VA)_{98}$	0.558**	0.435 **
$(ICT/VA)_{98}$	0.132*	0.748*
$LnEMPL_{98}$	0.007	-0.001
D. SPINOFFS	0.049	0.038
D. M&A	-0.042	-0.017
D. Textiles	0.080**	0.069**
D. Clothing	0.062	0.069
D. Leather	0.124*	0.107***
D. Wood	0.089*	0.135***
D. Pulp	0.024	0.001
D. Printing	0.079	0.089**
D. Chemicals	0.018	-0.026
D. Rubber	0.028	0.054
D. Non-metallic mineral products	0.062	0.044
D. Basic metals	0.062	-0.001
D. Metal products	0.018	0.049*
D. Mechanical engineering	0.015	0.072**
D. Office & electrical machinery	-0.074	0.012
D. Electronics, Radio-TV Equipment	-0.022	0.050
D. Transport vehicles & equipment	0.064	0.034
D. Miscellaneous manufacturing	0.072	0.096***
R-squared	0.023	0.026

Heteroskedasticity-robust standard errors. *=significant at 0.1; **=significant at 0.05; ***=significant at 0.01.

Table 7 - Determinants of TFP log differences 1998-2000: specification with lagged ICT intensity (LONG sample; 1119 observations)

	1	2	3	4
Constant	-0.083*	-0.081*	-0.081*	-0.070
$(R\&D/VA)_{98}$	0.533**	0.550**	0.532**	0.521**
$(ICT/VA)_{97}$	0.790**			
$(HWICT/VA)_{97}$		0.892*		
$(SWICT/VA)_{97}$			1.833	
$(COMMICT/VA)_{97}$				16.346**
$lnEMPL_{98}$	0.006	0.006	0.006	0.004
D. SPINOFFS	0.049	0.049	0.051	0.035
D. M&A	-0.039	-0.039	-0.039	-0.038
D. Textiles	0.081**	0.081**	0.080**	0.079**
D. Clothing	0.054	0.055	0.055	0.059
D. Leather	0.126*	0.125*	0.124*	0.124*
D. Wood	0.090*	0.089*	0.089*	0.086*
D. Pulp	0.026	0.025	0.026	0.025
D. Printing	0.083*	0.086*	0.087*	0.082
D. Chemicals	0.018	0.019	0.014	0.009
D. Rubber	0.027	0.027	0.027	0.029
D. Non-metallic mineral products	0.063	0.063	0.062	0.062
D. Basic metals	0.062	0.062	0.061	0.056
D. Metal products	0.016	0.017	0.016	0.014
D. Mechanical engineering	0.013	0.013	0.014	0.012
D. Office & electrical machinery	-0.070	-0.072	-0.070	-0.071
D. Electronics, Radio-TV Equipment	-0.023	-0.023	-0.022	-0.027
D. Transport vehicles & equipment	0.064	0.064	0.064	0.063
D. Miscellaneous manufacturing	0.070	0.071	0.071	0.075
R-squared	0.024	0.023	0.023	0.027

Heteroskedasticity-robust standard errors. *=significant at 0.1; **=significant at 0.05.

5. Concluding remarks and further extensions

The Italian private sector and its manufacturing industries perform little R&D activities as compared to the US and the major countries of the European Union. In terms of ICT investment the gap with other EU countries is less pronounced, albeit Italy records a different composition of these investments, with a greater share devoted to communication equipment. In any case, notwithstanding the increasing ICT outlays of the second half of the 1990s, Italian firms share with their European counterparts a substantial delay with respect to the US.

In the current debate on economic policies, the technological weakness of the Italian industrial system is included among the main causes of its recent decrease of competitiveness which appears so severe to lead many influential economists to evoke the ghost of a real "industrial decline". We share such a fear and believe that urgent and substantial policy interventions are needed in order to enhance the technological capability of Italian firms. The recent decrease in the R&D expenditures of the largest companies (documented also in this paper; for a further and detailed evidence see Sterlacchini, 2004), the low and declining presence of high-tech industries and a still not satisfactory diffusion of ICT are particularly worrying.

Albeit preliminary (see below) and limited to manufacturing firms, the piece of evidence provided in this paper suggests that policy measures aimed at supporting private investments in R&D and ICT are likely to be rewarding. This moderate optimism arises from the fact that, although in Italy there are not many R&D- and ICT-intensive firms, those with above-average technological performances have recorded in recent years the highest rates of productivity growth. Thus, at micro level, the estimated returns to R&D and ICT investments are significant and substantial. The latter, however, require some lags before productivity gains can be achieved. According to the "delay hypothesis" (and in line with the suggestions arising from previous studies), our findings indicate that, in order to be effective, ICT investments need to be coupled with complementary outlays in other intangible assets and organisational changes: examples of these additional efforts are the re-training of employees, the re-distribution of tasks and the re-design of decision-making processes. As a consequence, it must be stressed that if the Italian firms will not implement this consistent strategy of re-organisation, public incentives to invest in ICT (but also in R&D) will probably fail to enhance their competitiveness.

As already said, our results are encouraging but should be considered preliminary;

their main (econometric) drawback relies on the possible endogeneity of the R&D and ICT variables that could have biased our estimates. A procedure that should be adequate to address this issue would be that of estimating simultaneously a system of three equations: one for the TFP growth and the other two for the intensity of R&D and ICT. However, for the latter equations a Tobit estimation procedure must be performed because the OLS technique will probably produce inconsistent estimates due to censoring: in fact, 66% of the firms included in our sample did not report R&D expenditures and a lower but not negligible share of them (29%) did not report ICT outlays.

The estimation procedure for such a complete model could be carried out via maximum likelihood, along the lines of Maddala (1983, Chapter 7); we shall attempt to accomplish this (not trivial) task in the near future.

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