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ICT PRODUCTIVITY AND FIRM PROPENSITY TO INNOVATIVE INVESTMENT: LEARNING EFFECT EVIDENCE FROM ITALIAN MICRO DATA

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Abstract
This work attempts to shed light on the "information technology productivity paradox". Employing a large data set of Italian manufacturing firms we compute ICT marginal productivity across different cluster of firms and the impact of information and communication technology (ICT) on output growth. Following Yorukoglu's (1998) vintage capital idea, in which ICT is associated with consistent learning-by-doing effect, we explore whether firm capital replacement/introduction behaviour and firm's technological investment aptitude have any role in explaining ICT productivity. We find that low capital replacement (high capital introduction) yields to sensibly greater ICT marginal revenues compared to high replacement (low capital introduction). However, what really matters in explaining ICT productivity is the level of innovation the new capital embodies. In fact, for non-innovative firms the ICT paradox is far less consistent. This strongly suggests the existence of learning by doing effects. In terms of growth contribution we find that ICT have an impact disproportionately wide compared to the share in total investment they represent.

Keywords: *Growth, investment behaviour, information and communication technologies, productivity, replacement.*

JEL classification: *D21, D24, L2 O3*

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Introduction

In modern economies ICT has become progressively more important. According to the Bureau of Economic Analysis estimates in the two decades 1970-90, constant dollar investment in office and computer apparatus showed an average growth rate of about 18 percent compared to the 3.3 durable equipment percent rate in the remaining productions. Rapid improvements in the price-performance ratio of ICT (deriving from substantial and continuous technical advances) might well be at the base of the ICT substitution at the expenses of other form of capital assets and labour. This has been particularly pronounced in U.S. where in 1999 investment in ICT assets accounted for almost one-quarter of total nominal investment in fixed assets. It appears that firms are been strongly engaged in ICT endowments probably with the aim of getting performance improvements. This may supply an answer to the "information technology paradox" according to which too much ICT yields to productivity reduction, indicating over-investment in ICT.

A number of scholars have explored the link between ICT and productivity growth at firm level base. Although some research concludes negative or insignificant effects deriving from ICT (Loveman, 1994, Berndt and Morrison, 1995 among others), from the beginning of 1990s consensus is growing around this link being greatly positive. Using a data from over 300 of the largest US firms during the period 1988-1992 Brynjolfson and Hitt (1995, 1996) find that the gross marginal product of IT considerably exceeds its costs and that IT makes an important contribution to firm output when accounting for individual firm productivity differences. Employing data on the use of IT rather than the size of investment on French data Greenan and Mairesse (1996) and Greenan, Mairesse and Topiol-Bensaid (2001) observe positive correlations between computers and productivity. The same positive results are reached in Lichtenberg (1995), Barua and Lee (1997) and Lehr and Lichtenberg (1999). Siegel (1997), based on very detailed data for United States manufacturing industries, find strong evidence of positive correlations between ICT and firms performance.

Brynjolfsson and Hitt (2000a) conclude that IT benefits on productivity growth are even larger when longer-term returns are considered. Following a Tobin's *q* line, Brynjolfson and Yang (1997) find that while 1$ of traditional capital receives approximately the same amount value in the financial markets, 1$ of IT capital is correlated with some 10$ of additional stock market value suggesting a strong relevance of intangible assets costs. Schreyer (2000), for the G7 countries finds that ICT capital goods are important contributors to output and labour productivity growth but there is weak evidence that they are different from other capital.

Morrison and Berndt (1991) examined a set of production models employing a broad data set encompassing the whole U.S. manufacturing sector. They found that every dollar spent on IT delivers on the margin a return of only about $0.80, indicating a general over-investment in IT. On the other hand Brynjolfsson and Hitt (1993) and Lichtenberg (1995) conclude that for the firms in their sample, marginal return of IT investment strongly exceeds the marginal return of conventional capital investment, suggesting under-investment in IT capital.

This paper tries to compute ICT marginal productivity in a large sample of Italian firms during the period 1995-1997. Successively, we explore if there is any relationship between ICT productivity and firm's technological aptitude. Finally we assess the impact of ICT investment on output growth.

In line with several studies we find a small marginal return of ICT capital. This is also the preliminary result we reach in Atzeni and Carboni (2004). However, in that work we conclude that this picture might be misleading. Differentiating by the level of human capital and ICT investment we find that the way firms combine them (*matching*) has strong outcomes on the ICT marginal productivity. Matching firms show an ICT productivity about three times bigger compared to non-matching firms.

Here we further investigate this "suspicious" low level of ICT productivity and check if it might be affected any firm investment behaviour. Our concern, in particular, is to see whether *a*) the allocation of investment to additional or substitutive capital and *b*) its innovative level play any role in the explanation of ICT productivity.

According to Yorukoglu (1998) information technology intrinsically differs from conventional capital as for the rate of technological advance, the compatibility between old and new capital and the extent of learning by doing. Particularly, ICT investment is lumpier than conventional capital requiring larger and more frequent learning. Using a model where replacement (i.e. the substitution of expired capital for new one) is explicitly considered, he finds large drops in productivity at replacement dates. Since his notion of replacement only considers innovative investment, learning-by-doing is implicitly associated to the level of innovation the new capital embodies. He concludes that learning by doing together with the very nature of information technology can be at the base of downward bias of ICT productivity estimate.

Following this idea in this work we specifically distinguish firm investment behaviour according to the allocation of additional or substitutive capital on the one side, and innovative or technologically standardised capital on the other.

Consistently with the prescriptions of vintage capital models we find that, the technological level of new investment seems to matter enormously in the paradox story. Firms either replacing or introducing new capital perform a far greater ICT productivity if they adopt non-latest technology. Firms replacing with innovative investment show the lowest ICT productivity. This strongly supports the presence of learning by doing effects.

In terms of growth contribution we find that ICT have an impact disproportionately wide compared to the share in total investment they represent.

We are unable to distinguish between various types of capital and ICT capital stock is not available from the data set. Our main methodological concern is then to look for a measure of ICT productivity avoiding the usual caveats on ICT capital stock measurement. A Partial Price Change procedure is adopted working at price rather than output level.

The paper is organised as follows: section 2 contains a description of data set. Section 3 outlines the methodology employed. Section 4 provides the main econometric findings for ICT productivity. Section 5 furnishes some considerations on the ICT contribution on output growth. Section 6 contains the conclusions.

2. The data

The data used in this paper come from the Survey of Manufacturing Firms (SMF) carried out by an Italian investment bank, Mediocredito Centrale in 1998. The SFM considers a stratified sample of Italian firms from 11 up to 500 employees. Stratification is made according to the number of employees, sectors composition and location, taking as benchmark the Census of Italian Firms. It also includes all manufacturing firms with more than 500 employees. The SFM contains both questionnaire information about firm's structure, its behaviour and nine years balance sheet data (1989-1997). Information about ICT expenditure is displayed as a three-year level (1995-1997), while data on the stock of ICT capital are not provided. After all the necessary tidying we end up with a sample of 1923 observations.

Table 1 reports some descriptive statistics, particularly on the ICT related measures. For the whole period, average value added is close to 18.6 billions of Italian liras (around 9.6 millions euros) and average labor force is around 184 employees. Firms' ICT investment appears to be rather low both considering its share on value added (1.2%) and on total investment (12%). ICT investment per worker is slightly above 3 millions liras (1550 euros), indicating a quite slow process of new technologies adoption. Value added growth rate is less than 6 percent.

Firms are then gathered according to the replacement and innovative level of their investment. This gives eight sub-samples (see appendix for clustering criteria). A brief comparison among them gives some interesting base lines.

Spending 16 percent of their total investment in ICT, *high*-REP firms show a greater technological vocation with respect to the *low*-REP ones (7%). They also have a ICT Investment on value added 50 percent higher and ICT investment per worker about twice as much as in the *low*-REP counterpart. For non-ICT investment the situation is obviously reversed (13% *vs.* 25%).

Although technologically investing firms perform about twice as better (7.5% *vs.* 4.1%) and invest considerably more in ICT, they are similar to the *low*-INNO firms in terms of employees and total value added.

Interestingly, considering ICT investment, value added and labour force, the *high*-INNO cluster looks pretty similar to the *low*-REP one, with the exception of the growth rate of value added (7.5% *vs.* 5.9%).

Other interesting descriptive evidence comes from the additional four sub-groups obtained combining replacement with the degree of innovation of the new investment. The cluster of *high*-REP-*high*-INNO firms accentuates some of the two parent group characteristics. These firms are the biggest ones (24 billions of liras of value added and 237 employees) and have a share of ICT over total investment around 22 percent (2 percent of total value added). No other group shows a similar pace in adopting information technologies.

In table 2 the sectoral composition is displayed. One fourth of firms (24.8%) produce industrial and commercial machinery and about 35 percent operate in traditional sectors, like food, textile, leather, wood and paper. These latter are more represented in the *high*-REP (37.7%) and the *low*-INNO groups (39.7%).

It is worth noting that in the *high*-INNO cluster, industry machinery and electrical equipment sectors account for one third of the sample and for the same amount the traditional sectors. For the *low*-INNO group, on the contrary, the machinery industries are very low represented, summing up to only 18 percent. This is in line with the common picture where traditional sectors show a lower high-tech inclination particularly in the Food and Fabricated metal industries.

Combining the replacement behavior and the degree of innovative investment no substantial differences are highlighted and industry composition appears quite homogeneous.

3. Methodological concerns: TFP computation.

In this section we derive a measure of TFP from a Cobb-Douglas production function:

(3.1) $Y_{i,t} = Kict_{i,t}^{\beta}\ Koth_{i,t}^{\alpha}\ N_{i,t}^{\ 1-\alpha-\beta}\ A_i e^{\lambda t}$

where Y , *Kict*, *Koth* and N stand respectively for value added (VA), ICT, other capital and labour force, and the exponential trend is included to approximate other forces affecting productivity. Subscripts refer to the *i-th* firm and time. The parameter A is constant and λ is the rate of disembodied "external" technical change. Constant returns to scale are assumed.

Differentiating with respect to time and neglecting subscripts, equation (3.1) can be expressed in terms of total factor productivity:

(3.2) $y = \beta\ k_{ICT} + \alpha\ k_{OTH} + (1-\alpha-\beta)\, n + \lambda$

(3.3) $y - \ \alpha\ k_{OTH} - (1-\alpha-\beta) n = \lambda + \beta\ k_{ICT} = tfp$

where lower case letters represent rates of growth.

Recalling that the rate of growth of ICT capital stock is not available in the sample it may come useful to rewrite equation (3.3) in an alternative way. Considering that:

(3.4) $\beta = \dfrac{\partial Y}{\partial K_{ICT}} \cdot \dfrac{K_{ICT}}{Y}$ and

(3.5) $\beta\, k_{ICT} = \dfrac{\partial Y}{\partial K_{ICT}} \cdot \dfrac{K_{ICT}}{Y} \cdot \dfrac{\dot{K}_{ICT}}{K_{ICT}} = \dfrac{\partial Y}{\partial K_{ICT}}\ \dfrac{\dot{K}_{ICT}}{Y}$

where dots represent variations

and since $\dot{K}_{ICT} = I_{ICT}$

equation (3.3) becomes:

(3.6) $tfp = \lambda + \beta\ k_{ICT} = \lambda + \rho\ \frac{I_{ICT}}{Y}$

ρ 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 3.6 has a convenient feature: it allows us to calculate the marginal product of the stock of ICT capital without a measure of its level.

The further step is now to find an appropriate measure of the rate of growth of TFP. We compare two different measures of productivity. In the first one the rate of growth of TFP is given by the following:

(3.7) $tfp_{i,\,1995\text{-}97} = [(\ln Y_{i,1997} - \ln Y_{i,\,1995}) - \ln (DP_i) - ALS_{i,\,1995\text{-}97} \bullet (\ln N_{i,1997} - \ln N_{i,1995}) - (1 - ALS_{i,1995\text{-}97}) \bullet (\ln K_{1997} - \ln K_{1995})]$

where Y is value added, DP is the 1997 price index (1995=1.00) of manufacturing goods at industry level, ALS is the average share of labour cost on value added, N is the number of employees and K is the gross book value of fixed assets.

An approximation of TFP is given by the price-quantity *duality* (Griliches, 1973):

(3.8) $\text{tfp}_{i,\,1995\text{-}97} = [\text{ALS}_{i,\,1995\text{-}97} \bullet \ln \text{DW}_{i,1997} + (1 - \text{ALS}_{i,1995\text{-}97}) \bullet \ln \text{D}\Pi - \ln \text{DP}_{i,\,1995\text{-}97}]$

where ln DW is the change in average wage rate and ln D Π is an index of the rate of change in the service price of capital. As it is reasonable to consider this latter as constant over all manufacturing industries, we can rearrange equation (3.8) as follows:

(3.9) $\ln \text{DP}_{i,\,1995\text{-}97} - \text{ALS}_{i,\,1995\text{-}97} \bullet \ln \text{DW}_{i,1997} = \text{PP}_{i,\,1995\text{-}97} = -\,tfp_{i,\,1995\text{-}97} - \text{ALS}_{i,\,1995\text{-}97} \bullet \ln\ \underline{\text{D}\Pi}\ + + \ln \underline{\text{D}\Pi}$

The left hand side of equation (3.9) is defined as *Partial Price change* (PP). Given ln D Π constant across industries[1] it is possible to use PP as the dependent variable in equation (3.6) with ALS as an additional

[1] It is plausible that this assumption is violated due to capital market imperfections for example. However, these are less likely to be significant across industries.

regressor and obtain the parameter ρ, i.e. the marginal product of ICT capital. From (3.6) and (3.9) we obtain the equations for the estimation:

(3.10) $tfp = \lambda + \rho\, I_{ICT}/Y + \varepsilon$

(3.11) $PP = \lambda + \rho\, I_{ICT}/Y + \beta\, ALS + \varepsilon$

where subscripts have been omitted. Coefficients should be similar but of opposite sign. The coefficient of ALS is an estimate of the unobserved rate of change in the service price of capital.

In the following we use the *PP* method. Since its computation does not employ any measure of ICT capital (which is not contained in our data set) it is more appropriate for our purposes. In fact, it does not assume constant productivity through the life of a plant leaving room to learning kind considerations.

4. Estimation of ICT marginal product

In order to obtain the marginal product of ICT capital *PP* (3.11) equation is (OLS) estimated:

(4.1) $PP = -\,0.814\, I_{ICT}/Y - 0.075\, ALS$

where the intercept term has been replaced by industry dummies for 14 sectors aggregated according to ISTAT-ATECO classification. Even if not completely satisfactory, this allows us to pick up some sectoral heterogeneity.

The rate of return of ICT capital is 0.814, which implies putting one additional dollar of ICT capital into service yields roughly $ 0.40 of output per annum. This looks pretty consistent with the findings of other recent studies.[2] 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.[3]

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[2] Employing Canadian industries data Gera *et at* (1998) for example, find that the private rates of return on real (quality improvement in computers based on hedonic prices) IT investments are found to be about 30 percent per year. In Atzeni and Carboni (2004) a similar result has been obtained using the residuals to proxy productivity in a two-stage regression approach.

[3] As US Department of Commerce (1997) underlines, rental price of capital is generally only a fraction of the price of capital asset since it is based on interest, depreciation and possible capital gain or loss. For ICT capital rental price is unlikely to exceed $.0.5 for every $ 1 worth of capital assets. Employing company data Brynjolfsson and Hitt (1995)

The same regression on *non*-ICT investment gives:

(4.2) $PP = -0.10\, I_{\text{no-ICT}}/Y - 0.067$ ALS

ICT productivity is about eight times greater than that for *non*-ICT investment. This is pretty similar to US department of Commerce (1997) where coefficients are respectively 0.80 and 0.08.

In line with the main literature ICT coefficients appear to be rather small leaving, so far, the paradox essentially unsolved. However, according to Yorukoglu (1998) the ICT productivity paradox arises because the estimation is biased downward due to the assumption of constant productivity through the life of a plant. In presence of a strong learning-by-doing effect associated to new capital this latter statement is far to be true. So, we turn the attention to specific firm investment features and see if this may help shedding some light on this fact. The replacement activity and the technological composition of new investment is what we will be looking at in the following.[4]

4.1. The introduction-replacement issue

At each period firms must decide how many old machines must be scrapped and how much to invest in new ones (Boucekkine *et al.*, 1997). Information technology is different from conventional capital as for the rate of technological advance, the compatibility between old and new technology and the extent of learning by doing (Yorukoglu, 1998). More precisely, ICT investment is lumpier than that in conventional capital requiring more substantial and more frequent learning. Using a model where replacement is explicitly taken into account and where more efficient capital goods are available in each period, Yorukogulu (1998) finds large drops in productivity ("learning profile") coinciding with replacement dates. He concludes that learning by doing together with the very nature of information technology play a crucial role in explaining the downward bias of its productivity estimate. A one-year increase in a firm's average age of IT capital increases its output by around 2%, suggesting a strong learning-by-doing effect associated with it. A similar

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find that ICT net benefits are enough high to reject the hypothesis of zero returns even if the annual rental price is assumed to be $0.69.

[4] Contrarily to a priori expectations controls for size do not reveal ICT productivity asymmetries across the samples.

conclusion is reached in Bahk and Gort (1993) where one-year change in the average age of capital produces 2.5-3.5 percentages changes in production.

The point is why replacement (introduction) should yield to lower (higher) productivity (Cooley *et al.*, 1997). In fact, replacing with innovative capital has two conflicting outcomes. On the one side, according to the embodiment literature, there is a positive effect deriving from the new (and more efficient) technology it incorporates. On the other side, technological advances bring uncertainty due to learning, compatibility and organizational effects (Bresnahan *et al.*, 2002, Brynjolfsson and Hitt, 2000b). This latter negatively affects productivity.

However, Yorukoglu's notion of replacement only considers innovative investment. Although more efficient conventional and ICT capital become continuously available, not necessarily it is adopted by firms. What can be observed in the reality is that firms also invest in technologically standardised (equivalent to already owned) capital. [5] If firms introduce latest technological equipment the two above conflicting points come out. When new capital is equivalent, those problems might be mitigated by the fact that no hard-uncodifiable information is embodied and that it already has a compatible position in the productive process. We would aspect smaller learning and reorganizational effects in this latter case.

The question becomes then which is the overall effect and to which extent the learning associated to investment has outcomes on ICT marginal effects.

All this brings to the vintage capital issue: the compatibility between existing and new capital. According to Yorukoglu's (1998) model the benefit of an extra unit of capital is the present value of its marginal product multiplied by a compatibility index (c_τ) between new and old tecnology.

However, the compatibility index (c_τ) is not easily empirically discernable/distinguishable form the marginal product of the new capital installed (MR_{ICT}).

Empirically this implies that the ICT estimated parameter (ρ) is a "raw marginal product of capital": $\rho = MR_{ICT} \bullet c_\tau$

[5] Roughly 50% of firms in our dataset explicitly declare to have invested in equivalent technology.

If capital gives greater compatibility problems the estimated ρ will be lower as the increment of efficiency of ICT capital is only c_τ times the actual investment. The higher the degree of innovation the lower the compatibility index, resulting in a lower marginal product. On the contrary, we would expect higher estimates of ρ when investment is less innovative and when introduction of new capital take place.

With this framework in mind firms are grouped according to the way they either replace or add capital and to the innovative level of their investment in order to see if asymmetries in ICT productivity show up.

Firstly, we split the sample into *low* and *high*-replacing firms. Regression on the *low*-replacing (*high*-introduction) group gives now a substantial different picture (see appendix for groups and variable construction and table 4 for estimation summary):

(4.1.1) $PP = -2.10\ I_{\mathrm{ICT}}/Y - 0.11$ ALS

ICT productivity consistently increases, strongly undermining the paradox. This appears even sounder considering that the same coefficient is 0.25 for the *high*-replacing group.

However, differently from Yorukoglu, our notion of replacement also includes the case of non- innovative technology. This allows us more sample stratification and additional enquiring. Particularly, in the light of the technological level, the two groups above look sensibly different. The median technological level of investment is about four times bigger for the *high*-replacing firms. This supplies a strong reason to think that differences in the two groups are more related to the innovative level of their investment rather than to replacing-introduction behavior.

Splitting the sample according the innovative level of their investment we get for the *low*-innovative firms:

(4.1.2) $PP = -3.32\ I_{\mathrm{ICT}}/Y - 0.09$ ALS

and for the *high*-innovative firms:

(4.1.3) $PP = -0.57\ I_{\mathrm{ICT}}/Y - 0.05$ALS

Although for this latter group results are statistically not significant it emerges a clear relationship between the ICT productivity and technological level of investment.

We turn now the attention to what happens when further differentiating by the level of technology adopted within the *low*-replacing and the *high*-replacing firms. [6]

For the *low*-replacing and *low*-innovative firms we get:

(4.1.4) $PP = -\ 3.98\ I_{ICT}/Y - 0.03$ ALS

In line with *a priori* expectations results appear reinforced when we relax the hypothesis that new capital is always innovative (embodies new technology): *low*-replacing firms perform a far greater ICT productivity if they introduce non-latest technology. *High*-innovative firms show, in fact, an ICT coefficient of 2.0. [7]

A similar picture comes out for the *high*-replacing firms: again productivity is particularly sensitive to changes in innovation. [8]

This is consistent with Yorukoglu (1998) where at the replacement date productivity sensibly drops due to learning dynamics associated with new and innovative capital. Rapid technological improvements in ICT capital bring standardization problems implying a weak compatibility between different vintages of IT capitalDescriptive statistics in table 1 may supply some additional interesting facts. The *low*-rep & *low*-inno group, the most productive one, invests in ICT far less (far more in *non*-ICT) than the sample mean and performs a lower output growth. Given their low level of ICT investment (as share in total output), firms introducing rather than replacing capital and adopting "non-leading" technologies, make ICT investment work pretty efficiently. This might be partly explained by learning considerations as well as by marginal kind effects. Little and non-frequent investment favors the exploitation of the *apprentisage* term which, is not continuously interrupted by changes in the capital composition (e.g. new and innovative). On the other hand, consistently with *a priori* expectations, these firms invest more than the average firm. The considerations above apply now on the opposite

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[7] Furthermore, although group coefficients difference is wide, it seams that it is the *low*-rep & *high*-inno group that strongly determines the overall low-replacing group ICT productivity. This is driven by the fact that, in spite of its sensibly greater coefficient, the *low*-rep & *low*-inno group ICT investment share in total output only represents less that half of the of the corresponding *low*-rep & *high*-inno counterpart.

[8] For *non*-ICT investment relations appear reversed.

direction and high returns on ICT would be the consequence of sub-optimal ICT investment decision. However, although we cannot discern those effects, it is likely to be a temporary condition.

5. ICT contribution to output growth

Given the average value of I_{ICT}/Y (0.012) and of the marginal product of ICT capital, its contribution to output growth is straightforward, resulting approximately 0.50 percentage point (1/2•0.814•0.012) per annum.[9] When disaggregating the sample according to the way firms replace capital and their technological aptitude further and sounder support on the role ICT has on growth (table 3). For *non*-ICT investment the same contribution is 1.0 percentage point.

Unfortunately there are very few micro studies on Italy to make comparisons.[10] Nevertheless, it is worth mentioning that employing Italian macro data, in Daveri (2001) the same contribution is 0.35% per year for the period 1996-99 and 0.28% per year for the period 1991-95, while Schreyer (2000) finds 0.21% per annum during the period 1990-96 (0.7 for other capital) in Italy. However, in this latter work only hardware ICT capital is considered, as the author himself underlines, neglecting software ICT implies consistent underestimation of this coefficient.

On US data, Oliner and Sichel (2000) find an ICT hardware contribution of 0.63% during the period 1996-99. Over the same period, according to Jorgenson and Stiroh (2000) the contribution was 0.49%. Whelan (2000) calculates that the use of computer hardware contributed approximately 0.8% to output growth during the period 1996-98. Gordon (2000) and Jorgenson-Stiroh (1999) find that the annual overall contribution of computer to output growth in the second half of 1990s

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[9] These values are smaller than what generally found in US. This may be due to the lower share of ICT assets in total capital stock, 2.1 *vs.* 7.4 in US in 1996 (Schreyer, 2000). It should be noted that in Italy (as in some other European countries) ICT investment has been concentrated in service industries. Although they occupy a relative small role (differently from US and UK) in the economy, accounting for this sector (non available in the data set) greater values are to be expected.

[10] Using the perpetual inventory method to compute the ICT capital stock, Bugamelli and Pagano (2001) estimate an elasticity of about 4%, implying a marginal product sensibly higher than its user cost. Gambardella and Torrisi (2001) estimate the impact of ICT investment on TFP, but they do not provide any measure of the marginal product of ICT.

is close to 1%. Melka et al. (2003) on French macro data find that the contribution of ICT to value added is about 0.46% per year over the period 1995-2000.

Taken as such our results may appear poorly indicative. However, in spite of its lower importance, both in terms of total investment (7 times smaller) and output (15 times smaller) ICT investment accounts for a relevant share of output growth with respect to *non*-ICT investment. In terms of proportion of total output growth the importance of ICT investment as a contributor appears even stronger, being approximately 17% against 33% of other investment. This simply means that ICT investment, which only represents 12% of total investment and 1.2% of total output, accounts for 34% of total investment growth contribution (17% of 50%). This is certainty a relevant issue and states that ICT is relatively far more important than other form of capital investment.

Again, it is in line with available evidence. On Italian macro data Schreyer (2000) calculates a 17.5% contribution of ICT equipment (basically hardware) to total business sector output growth while it only accounts for 2.1 percent of total productive capital stock.[11] On UK macro data Oulton (2001) finds that despite its small share in GDP, ICT accounted for 18.2% of output growth and 0.57 percentage point of annual contribution to GDP growth is during the period 1994-98.

6. Concluding remarks

This work attempts to move a small step towards the comprehension of general low ICT productivity evidence. Preliminary results are pretty similar to general literature, keeping the information paradox issue essentially unsolved. However, we find that this only partially tells the story giving a misleading picture of what actually happens in the extent of specific firm. In fact, there are good reasons to believe that, taken as such, ICT productivity is downward estimated.

Our main finding is that ICT productivity is strictly linked to firms' investment behavior. Differentiating the sample according to the firms' aptitude to either adopt or replace ICT investment the story looks quite different.

When investment is mainly guided by replacement activity the average firm behaves notably worse than the remaining ones. Such firms

[11] On US data, the same share is 14% in Schreyer (2000) during 1990-96, 19% and 23% respectively for 1990-96 and 1996-99 in Oliner-Sichel (2000).

show an ICT productivity enormously smaller relatively to the *low*-replacing (*high*-introducing) ones. Within these latter ICT appears particularly efficient instead. However, such efficiency is linked to the technological level, which is consistently different in the two groups. This supports the intuition that asymmetries in the two groups are more related to the innovative level of their investment rather than to replacing-introduction behavior. In fact, a similar result is found splitting the sample according to the degree of innovative investment, suggesting the presence of learning by doing processes. This is also confirmed across the sub-samples. Within the *low*-replacing group, the cluster of firms investing in standardised technology shows the highest ICT productivity.

Investing in non-leading technologies appears to be both more remunerable and more effective in terms of output growth compared to investing in ICT capital substitution. This latter statement would be hard to accept without any further consideration about ICT investment own specificities. While it is relatively easy for firms to (over-)invest in ICT, this process requires some adoption time. Furthermore, fast technological improvements in ICT capital lead to standardization problems. If replacement occurs along the learning curve growing side of the already installed ICT, old and still cumulating benefits are likely to be lost. Contemporaneously, new frictions ladder technology brings with enter the production process. Continuous capital renewing *per se* does not necessarily represent the best solution if it requires cumulative learning process that ought not be skipped or interrupt. Relative smaller short-term marginal productivity is to be expected as a signal of the ICT integration and learning state.

Another implication of our findings is that ICT investment is much more important than *non*-ICT investment in determining output growth. In line with Brynjolfsson and Yang (1997), Brynjolfsson and Hitt (1996, 2000), Jorgenson and Stiroh (2000) and Whelan (2000), we state that rather being paradoxically under-productive, ICT have an impact on output growth which is disproportionately wide compared to the share in total investment they represent. This is even more evident if the technological composition of new investment is taken into account.

While it is not definitely clear the role learning process might have (data time horizon does not allow any further inquiry), it appears clear that other factors are involved in the whole process; reorganization, temporal lag and externalities among others. A critical part of the successful ICT implementation is firm's commitment to undertake complementary investment in physical assets, workforce reskilling and work practices to reap the potential benefits. Moreover, there are restructuring processes and costs cutting that are strongly requested. Complete analysis should be shaped such as to capture those factors in order to cast a brighter light onto the ICT *black box*. It is certainly an ambitious challenge and further research is strongly needed on these topics.

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Appendix

Dependent variable:

(Partial price change) PP= ln DP_i – $ALS_{i, 1995\text{-}97}$ • ln $DW_{i, 1997}$

Other variables:

K: gross book value of fixed assets

N: number of employees

L: labour outlays

Y: Value Added

DP: index of price change across firms. It is obtained weighting the 1997 price index of manufacturing goods at industry level ($PI_{1995=100}$) by a measure of firm mark-up (MUP_i):

ln DW: change in the average wage rate

$DP_i = PI_{1995=100}\ MUP_i$,

$MUP_i = [1 + (AVMKUP_{i, 1995\text{-}97} - 0.28)]$, where $AVMKUP_i$ is the average level of mark up in the period 1995-97 for firm i-th and 0.28 is AVMKUP median.

$$AVMKUP_{i, 1995\text{-}97} = \sum_{t=1995}^{T=1997} \frac{[(\text{sales}_{i,t} + \Delta\, inventories_{i,t} - \text{intermediate inputs}_{i,t}) / (sales_{i,t} + \Delta\, \text{inventories}_{i,t})]}{3}$$

$$ALS_{i, 1995\text{-}97} = \sum_{t=1995}^{T=1997} (L_{i,t} / Y_{i,t})$$

$$\ln DW_{i, 1995\text{-}97} = (\ln L_{i,97} - L_{i,95})\text{-}(\ln N_{i,97} - \ln N_{i,95})$$

Groups:

Rep: share of replacement over total investment, weighted by the share of ICT investment.

Low (*high*) replacement: firms below (above) the referring group median.

Inno: share of innovative over total investment, weighted by the share of ICT investment.

Low (*high*) innovative: firms below (above) the referring group median.

Tab. 1 - Descriptive statistics

Variable	Whole sample (N=1923)	*Low*-REP (N=962)	*High*-REP (N=961)	*Low* INNO (N=960)	*High*- INNO (N=963)	*Low*-REP *low*-INNO (N=486)	*Low*-REP *high* - INNO (N=476)	*High*-REP *Low*-INNO (N=481)	*High*-REP H*igh* -INNO (N=480)
PP	-0.033	-0.041	-0.025	-0.042	-0.023	-0.048	-0.033	-0.034	-0.016
Value Added (million of IT liras, mean 1995-97)	18,622.74	16,852.69	20,394.64	18,575.88	18,669.46	20,857.03	12,764.23	17,038.24	23,758.03
Labour force (mean 1995-97)	184.34	160.924	207.779	180.536	188.132	190.711	130.512	177.707	237.914
ICT investment on VA (mean 1995-97)	0.012	0.009	0.015	0.007	0.017	0.005	0.013	0.01	0.02
Other capital investment on VA (mean 1995-97)	0.191	0.25	0.132	0.255	0.127	0.31	0.189	0.163	0.101
ICT investment on total investment (mean 1995-97)	0.118	0.074	0.163	0.06	0.176	0.035	0.114	0.097	0.228
ICT investment per worker (million of IT liras) (mean 1995-97)	3.301	2.449	4.155	1.909	4.689	1.332	3.589	2.675	5.637
% rate of growth of VA (1995-97)	0.058	0.056	0.059	0.041	0.075	0.03	0.083	0.06	0.058

Tab. 2 Sectoral composition (sample and group means)

Variable	Whole sample (N=1923)	*Low*-REP (N=962)	*High*-REP (N=961)	*Low* INNO (N=960)	*High*-INNO (N=963)	*Low*-REP *low*-INNO (N=486)	*Low*-REP *high* -INNO (N=476)	*High*-REP *Low*-INNO (N=481)	*High*-REP H*igh* -INNO (N=480)
Food, beverages and tobacco	9.6	9.4	9.9	13.3	5.9	12.6	6.1	12.9	6.9
Textile	14.5	12.4	16.6	14.4	14.6	12.6	12.2	16.6	16.7
Leather, leather products	2.5	1.7	3.3	1.9	3.1	1.4	1.9	3.3	3.3
Lumber and wood products	2.8	2.6	3.0	3.2	2.4	3.1	2.1	3.7	2.3
Paper and allied products	6.1	7.3	4.9	6.9	5.3	9.7	4.8	4.0	5.8
Petroleum refining and related industries	0.6	0.9	0.3	1.0	0.2	1.2	0.6	0.2	0.4
Chemicals and allied products	4.6	5.0	4.3	4.8	4.5	5.6	4.4	4.4	4.2
Rubber and plastics products	5.9	7.2	4.7	6.6	5.3	7.8	6.5	4.4	5.0
Primary metals products	5.8	7.0	4.6	7.2	4.4	8.6	5.3	5.6	3.5
Fabricated metals products	12.6	14.9	10.3	14.6	10.6	16.5	13.2	10.8	9.8
Industry and commercial machinery	18.4	16.2	20.6	13.3	23.5	10.7	21.8	17.7	23.5
Electrical equipment	6.8	6.2	7.4	4.8	8.8	3.9	8.6	6.4	8.3
Motor vehicles	4.5	4.5	4.5	4.1	4.9	4.3	4.6	4.2	4.8
Furniture, fixture and miscellaneous	3.9	3.8	4.0	3.1	4.7	1.2	6.5	4.4	3.5

Tab. 3 – Estimation results (PP dependent variable)

Group	ρ ICT	F	Adj. R^2	Contrib. to growth (%)	ρ *non*-ICT	F	Adj. R^2	Contrib. to growth (%)
Whole sample (N=1923)	0.814 (t=3.19)	15.96	0.13	1.0	0.1 (t=6.23)	22.04	0.15	1.9
***Low*-rep** (N=962)	2.1 (t=4.81)	14.19	0.18	1.9	0.08 (t=4.45)	13.94	0.17	2.0
Low-rep & *low*-inno (N=486)	3.98 (t=2.83)	11.50	0.25	1.6	0.06 (t=2.71)	11.44	0.26	2.0
Low-rep & *high*-inno (N=476)	2.07 (t=3.91)	5.93	0.14	2.7	0.1 (t=3.70)	5.81	0.14	2.0
***High*-rep** (N=961)	0.25 (t =0.78)	7.97	0.10	0.4	0.16 (t=4.27)	9.22	0.12	2.1
High-rep *&* *low* –inno (N=481)	1.47 (t =2.04)	7.23	0.17	1.5	0.16 (t=3.60)	7.92	0.19	2.6
High-*rep* & high–*inno* (N=480)	0.19 (t =0.49)	2.77	0.05	0.4	0.14 (t=1.92)	3.01	0.06	1.4
***Low*-inno** (N=960)	3.32 (t=5.09)	18.93	0.23	2.3	0.09 (t=5.12)	18.95	0.23	2.3
***High*-inno** (N=963)	0.57 (t=1.86)	5.48	0.07	1.0	0.11 (t=3.43)	6.05	0.08	1.3

ρ is the parameter of IICT/Y regressor and represent the marginal product of ICT capital.
ρ non-ICT is the parameter of no-ICT/Y and stands for the marginal productivity of non-ICT capital.
Groups are obtained splitting the sample at the median value of the referring variable and group.
All estimations are carried out with sectoral dummies.
t statistics in parentheses