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BARRIERS TO INVESTMENT IN ICT

by Matteo Bugamelli* and Patrizio Pagano*

Abstract

We investigate the diffusion of information and communication technologies (ICT) in Italian manufacturing using microdata. We find a positive correlation at firm level between ICT investment, human capital of the labor force and reorganization. Starting from flow data, we build a measure of ICT capital stock, which includes hardware, software and communication equipment, showing a delay in ICT accumulation with respect to US manufacturing, in 1997, of about 8 years. We use this measure to estimate a production function. The elasticity of value added to ICT capital turns out to be close to 4 per cent, which implies an ICT marginal product much higher than its user cost. We argue that this can be explained by the presence of barriers to ICT investment such as the low level of human capital and the lack of reorganization of the firm.

JEL classification: D24, L23, O30.

Keywords: new economy, information and communication technologies, firm organization, human capital.

Contents

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1. Introduction[1]

The US economy has experienced in the nineties a period of sustained productivity growth, particularly in the second half of the decade. Labor productivity in the non farm business sector has grown at an average annual rate close to 2.7 percent, almost 4 percent in the manufacturing sector. As pointed out by Oliner and Sichel (2000), Jorgenson and Stiroh (2000), the Council of Economic Advisors (2000) and the Bureau of Labor Statistics (2000), the growth of labor productivity in the second half of the nineties with respect to the period 1973-1995 can be equally ascribed to capital deepening and total factor productivity (TFP) growth. In particular, it is the acceleration of the latter that makes the recent performance of the US economy quite a novel phenomenon.

The productivity revival has coincided with massive investment in information and communication technologies (ICT), fueled by strong computer price declines. In evaluating the contribution of ICT to labor productivity growth, Oliner and Sichel (2000) and BLS (2000) attribute the effect of capital deepening almost entirely to ICT; Jorgenson and Stiroh (2000) claim instead that ICT contribution is slightly smaller than that of other capital. TFP has increased more in the durable goods industries, in particular in that producing ICT goods. Caselli and Paternò (2001) investigate the relationship between TFP growth and ICT at sectoral level in the US. In ICT intensive industries and in the second half of the nineties, they find evidence of a positive correlation between the share of computer on ICT capital stock and TFP growth.

Analogous information on European countries is quite limited. Any study on Europe has first to face the problem of constructing a reliable measure of ICT capital stock. To our knowledge only two papers have dealt with this issue: Daveri (2000) and Schreyer (2000). Comparability between these two studies is precluded by relevant differences: in Daveri (2000) ICT capital stock includes software and refers to the business sector, while Schreyer (2000) analyzes the entire economy and focuses only on hardware and communication equipment.

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Yet, both papers point to a substantial delay of Europe — and Italy in particular — in the adoption of these technologies. Schreyer (2000) calculates that in 1996 the share of ICT in nominal productive capital stock was 2.1 per cent in Italy, while the corresponding value in the US was 7.4[2]. According to Daveri (2000), in 1997 the ICT capital-output ratio was 10.6 per cent in Italy and 13.5 in the US[3].

Some scholars have investigated the impact of ICT on productivity at firm or plant level: Black and Lynch (2000) and Bresnahan *et al.* (2001) for the US, Greenan *et al.* (2001) for France find a positive relationship between ICT capital stock and productivity. Inspired by various case studies[4], Black and Lynch (2000) and Bresnahan *et al.* (2001) go further and examine the interaction between ICT and other factors within the firm. Their idea is that two main changes must be implemented by firms adopting these new technologies: higher demand for skilled workers and workplace reorganization[5]. In order to make the use of computers and related technologies more productive, firms need a well educated labor force (able to use or to learn how to use computers efficiently), thereby characterizing the ICT revolution as a skill biased technical change (Autor *et al.*, 1998; Johnson, 1997). Moreover, since computers change the way and the speed by which information is produced and diffused, firms must accordingly change their internal functioning. As emerged from US firms' reorganizations, the trend is toward firm vertical dis-integration with a reduction of the number of managerial levels and more decentralized decision and productive processes[6]. In turn, this workplace innovations induce a further increase in the demand for skilled labor, influencing also the pace of research activity and thereby the rate of growth.

We use microdata on ICT investment contained in the Mediocredito Centrale Survey of Manufacturing Firms in Italy, which provides also information on workers' distribution in terms of education and skill and on the occurrence of firm reorganization. Indeed, we find a positive correlation between ICT investment, reorganization of the production process and

[2] In France and Germany ICT capital shares were, respectively, 3.2 and 3 per cent.

[3] Respectively, 10.8 and 13.4 in France and Germany.

[4] See Krafcik (1988), Ichniowski (1990) among the others.

[5] According to Black and Lynch (2000) workplace practice accounted for approximately 90 per cent of total factor productivity growth in US manufacturing in 1993-96.

[6] For example, thank to the cheaper monitoring over the entire production process made available by the new technologies, single workers are more autonomous and more frequently called to make crucial decisions.

the level of human capital in the labor force. Moreover, since a significant fraction of our sampled firms claim not to have invested in ICT at all, we estimate a probit model to capture the differences between firms with and without ICT: it results that the probability of ICT adoption is higher in firms that reorganized the production process. On the other hand, the amount of ICT investment is positively correlated with the level of human capital of the workforce.

Starting from investment flows, we then construct a measure of ICT capital stock for each firm. We show that in the whole Italian manufacturing, in 1997, the ICT capital stock was similar to the value recorded in the US in the late eighties. We also show that some of the backwardness of the Italian with respect to the US manufacturing is due to the different sectoral specialization, relatively more concentrated on traditional (and low ICT intensive) products in Italy.

It can be argued that the relatively low value of ICT capital among Italian firms is due to some barriers to investment. If this is true one has to observe, because of diminishing marginal returns, a relatively high marginal product of ICT capital. To test this argument we estimate and identify the parameters of a production function. The estimated output elasticity actually implies a very high marginal product of ICT capital, much higher than its user cost (as measured by the Jorgensonian rental price). If we select out firms that in the past three years experienced a reorganization of the production process and invested in human capital — firms that we qualify as "unconstrained" — we are able to explain the excess return to ICT capital: being not constrained by the lack of complementary investments, the former invest more in ICT and, given diminishing returns, they display a lower marginal product of ICT capital. Interestingly, we also find that firms that invested either in reorganization or in human capital are not very different, in terms of excess return, from those that did neither, suggesting that both a skilled workforce and the reorganization of the firm are essential for ICT accumulation.

The rest of the paper is organized as follows: in the next section we illustrate data characteristics and descriptive statistics, focusing on the differences between Italian and US manufacturing. In section 3 we examine the correlation between ICT investment, human capital and firm reorganization. In section 4 we construct the ICT capital stock for each firm, and compare the resulting value for the Italian manufacturing to that of the US. The estimation of the production function and the excess return argument is presented in Section 5. Section 6 concludes.

2. The data

We combine information from two sources: the "Centrale dei Bilanci" (Company Accounts Data Service, CADS) and the "Indagine sulle Imprese Manifatturiere" (Survey of Manufacturing Firms, SMF) by Mediocredito Centrale. For approximately 30,000 firms per year, CADS collects information on a large number of balance sheet items and some firm characteristics (sector of activity, location, cash flow, year of foundation). Mediocredito Centrale manages a survey on about 5,000 manufacturing firms. With respect to CADS, SMF contains a richer set of qualitative and quantitative information on firm's activity (workforce distribution in terms of education and function, process and product innovation, organizational changes, ownership and financial structure, etc.). More importantly, the last release of SMF, covering the period 1995-97, provides information on the total amount of investment in ICT during the triennium under analysis. Both sources are described in greater detail in Appendix A.1. Merging the two datasets and excluding firms with missing values on relevant variables, we end up with a sample of 2,398 manufacturing firms.

Table 1 reports some descriptive statistics. Firms in our sample ranges from a minimum size of 11 employees to a maximum of 10,200 with an average of 158. With a very low median size (48 employees), our sample reflects the peculiar Italian firm size distribution satisfactorily enough. The average firm age is 25 years; about one per cent of firms have been founded more than a century ago. The SMF contain details on the composition of the labor force in 1997 both in terms of educational attainment (college, high school and compulsory education) and type of occupation (manager, executive cadres, clerk and production workers). In Appendix A.2 we derive a measure of human capital based on average years of schooling: it ranges from 8 to 17 years, however the distribution is quite symmetric and concentrated around 10. We then aggregate managers, executive cadres and clerks into the category "white collar", denoting the production workers as "blue collar". Both in terms of mean and median the number of blue collar is twice as big as that of white collar. We also know if firms have performed some reorganization connected to process innovation, product innovation or both (see Appendix A.2): about 30 percent of firms have claimed some reorganizational change in the period 1995-97, mainly related to process innovation. Unfortunately, we have no details on the degree or the amount of resources involved in such changes.

As shown in Table 2, 60 percent of firms are located in the North, only 12 percent in the South. A high percentage of firms (17.5 percent) produce industrial machinery and equipment (excluding computer and office equipment); about 25 percent operate in traditional sectors, like textile, leather and food. Only 0.4 percent of firms produce computers and office equipment. Overall, although not perfectly representative, we believe our sample match population characteristics quite well.

In the second column of Tables 1 and 2, we present the same summary statistics for the subsample of firms that claimed zero ICT investment in 1995-97. Not surprisingly, these firms mostly belong to traditional sectors and are located in Center-Southern regions; they also display a significantly smaller average size, a smaller propensity to reorganization and to R&D.

3. ICT investment, human capital and organization

In this section we start investigating on the hypothesis that ICT is linked to human capital and reorganization. The goal here is to look just for simple correlations using the raw data on nominal investment in ICT over the period 1995-97. To this end, we regress ICT investment per employee over our measure of human capital, the dummy variable for reorganization and a set of other controls. Besides sector (Nace Rev.1 classification - two digits), location (North-East, North-West, Center, South), and ownership structure[7] dummies, the controls include a proxy for firm demand (sales per employee), that should be positively correlated with the level of investment, and the percentage of white collar, again positively correlated since these are workers whose daily activity is characterized by a relatively more intensive use of computers.

In column [1] of Table 3, we present the results of the OLS estimate over the full sample, including firms with both positive and null investment in ICT. The coefficients of human capital and reorganization are both positive and significant ($t - statistics$ are, respectively, 2.3 and 3.3). Not surprisingly, the higher the percentage of white collar workers, the larger is investment in ICT. Market demand has also a positive impact. For the other dummies, it is useful to know that our benchmark firm operates in the sector producing “textile and clothing”, is located in the northwestern region, belongs to a private entity and does not refer

[7] This is described by means of two dummies, one for public vs private ownership and one for group membership.

to any group. We find that firms belonging to a group invest more, while state-owned firms invest less. Sectors lagging behind are “petroleum refining and related industries”, “apparel and related products”, “leather and leather products” and “stone, clay and glass”; only firms in “printing and publishing” distinguish for a significantly higher level of investment in ICT. Interestingly, our estimates do not signal any difference in terms of firm location.

In our sample, 546 firms (23 per cent of firms) claimed no investment in ICT. It is then interesting to verify whether these firms have some specific features, i.e. whether different firm characteristics are correlated with the decision to make an investment and the choice of the amount to invest. In other words, we distinguish the investment from the adoption problem.

In column [2], we report probit estimates for the full sample. We find that the coefficient of human capital is not significant anymore, while the reorganization dummy is still positive and highly significant ($t-statistics$ 7.1). Quantitatively, reorganization of production process raises the probability to invest in ICT by 14 percentage points, equivalent to almost 20 per cent of the average probability. Interestingly, there are now differences in terms of location: all firms lag behind northwestern ones; however, firms in the South are not less likely to invest in ICT than those located in the North East: their probability is smaller by 7 percentage points with respect to northwestern firms. Finally, we restrict to the subsample of firms with strictly positive investment in ICT. We have first checked that the exclusion of the other firms does not imply any sample selection bias. In fact, having estimated our model through Heckman’s two-step procedure (Heckman, 1979) we found that we can safely proceed with OLS. In column [3], we report the latter estimates. The amount to ICT investment is positively correlated with human capital; the reorganization dummy has still a positive coefficient, which though is not different from zero at conventional levels.

To sum up, we find evidence of a positive correlation between ICT, labor force education and changes in the internal functioning of a firm. Speculating on these preliminary results, they suggest that since firm reorganization and investment in human capital seem to complement investment in ICT, the more the former are difficult to implement the larger the adjustment costs to ICT investment. In particular, we might say that reorganization seems to be quite important as a barrier to adoption supporting the hypothesis that new information and communication technologies impose somehow costly changes to the production process. On the other hand, the amount of investment in ICT parallels the skill level of the workforce:

as long as it is costly to change the average level of human capital, ICT investment will be limited.

4. ICT capital stock

We use information on ICT investment in 1995-97 to construct a measure of ICT capital stock at firm level. Our methodology, described in details in Appendix A.2, is crucially based on the dynamics of Italian imports of hardware, software and telecommunications equipment. We believe these data to be sufficiently informative, since in Italy the sector producing computer and related equipment is very small (only 1 per cent of Italian manufacturing value added in 1995)[8].

Briefly, we use imports data to derive yearly figures for 1995-97 and to project them backwards according to each item's service life[9]. To convert nominal into real investment flows so as to measure the relative efficiency of each vintage of investment goods, we use hedonic prices that better reflect quality changes. Unfortunately, these prices are not available for Italy; however, since we are dealing with goods that are highly tradable and whose prices are mainly set in US dollars, we confidently use the dynamics of US equivalent deflators (BLS, 2000), after having corrected for exchange rate variations[10]. We then apply depreciation rates[11] and derive ICT capital stock by the perpetual inventory method[12].

As a result of our calculations, we find that in 1997 the average share of real investment in ICT on real investment in machinery and equipment was 40 per cent with a considerably

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8 Caselli and Coleman (2001) make a similar hypothesis to analyze the diffusion of these new technologies across the world.

9 Fraumeni (1997) and Seskin (1999) compute a service life of seven years for hardware, four years for software and eleven years for telecommunication equipment.

10 The results do not change much if we do not make the exchange rate correction, as done by Schreyer (2000) and Daveri (2000).

11 According to service lives, we use the corresponding constant annual depreciation rates that are equal to 32, 44 and 15 per cent, respectively for hardware, software and telecommunication equipment.

12 The concept of capital stock used here is that of "productive" capital, obtained by summing various assets at constant prices. This differs from capital "services", obtained by summing the various assets using rental prices as weights.

lower median (12 per cent); these two figures raise, respectively, to 51 and 20 per cent when firms with zero ICT investment are excluded.

Table 4 shows the shares of ICT investment and capital stock over value added for each sector[13] in 1997. Given our methodology to derive ICT capital stock, the ranking of sectors is identical when derived from investment and stock data; we compute them both for the full sample and for the subsample of firms with strictly positive ICT investment. We find significant differences across sectors. For the full sample, the ICT intensive sectors are, in decreasing order, “computer and office equipment”, “printing and publishing”, “measuring and controlling instruments”, all three with a share of ICT capital stock over value added bigger than 10 per cent. At the bottom, we find firms operating in “petroleum refining and related industries”, “leather and leather products” and “primary metal products”. When we exclude firms with no ICT, the ranking remains more or less the same.

Given the lack of information at the aggregate level, it is then interesting to ask what our data imply in terms of aggregate ICT capital stock. To this purpose, we take our estimates of sectoral ICT investment and capital stocks and explode them to population by using value added weights (given by the ratio between the value added in the population and the value added in our sample for each sector). By adding up these values across sectors, we obtain a figure for the whole manufacturing. The results are reported in the last row of Table 4: investment is 2.2 per cent of value added, capital stock 4.9.

To gauge the technological lag of Italy, we compare these figures to the equivalent measure from US manufacturing (Figure 1). In 1997, the two figures for the US were, respectively, around 3 and 8.5 percent; looking back into US time series, Italian values are found around 1995 for investment and 1989 for capital stock. If we take the measure computed excluding zero ICT firms, the delay reduces by one year. Thus, overall, we can quantify Italian delay in ICT with respect to the US in about 8 years in terms of stock; the shorter delay in terms of investment rates might imply that some catching up is under way. Undoubtedly, at least part of this gap is due to the different sectoral specialization. In fact, in Italy traditional sectors (textile, leather, apparel), whose technologies are relatively less ICT intensive, produced in

[13] From our sample, we compute the ratio between the sum of ICT capital stock across firms belonging to a given sector and the sum of value added of those same firms.

1995 about 12 percent of total manufacturing value added, against a low 4.5 in the US. The situation is reversed in the more advanced (and ICT intensive) productions.

5. Production function

The evidence presented in the last section shows that in the Italian manufacturing ICT intensity, as measured by the ratio of ICT capital stock to value added, is relatively low, at least when compared to the analogous value in the US. This adds to the similar conclusions by Daveri (2000) and Schreyer (2000). As mentioned in section 3 the need of complementary investments might increase the cost to be faced when investing in ICT. These potentially large adjustment costs to the succesful use of ICT may result into a low ICT capital to value added ratio and a high marginal return to ICT capital.

To calculate the marginal product of ICT capital we estimate a production function. In particular, we assume that the production of the generic firm i can be represented by the following function

$$Y_i = F\left(H_i, K_i^{ICT}, U_i K_i^{OTH}, A_i\right) \tag{1}$$

where Y is value added, H is the amount of human capital-augmented labor, K^{ICT} is the stock of ICT capital, K^{OTH} is the stock of other capital[14], U is an index of the use of installed capacity and A is a productivity index. We assume that labor L is homogeneous within a firm and that each unit of labor has been trained with S years of schooling: human capital augmented labor is thus

$$H_i = e^{\phi S_i} L_i \tag{2}$$

where S_i is firm average years of schooling; ϕS reflects the efficiency of one unit of labor with S years of schooling relative to one with no schooling $(S = 0)$. The derivative ϕ is the return to schooling in a Mincerian wage equation; Bils and Klenow (2000) suggest that this is the appropriate way to incorporate years of schooling into a production function. This

[14] See Appendix A.2 for the derivation of total and other (i.e., different from ICT) capital stock.

specification is enriched to include a split of labor between production (blue collar) and nonproduction workers (white collar), $L_i = W_i^{\alpha} B_i^{1-\alpha}$.

Since many information relates to the entire triennium 1995-97 without any yearly breakdown, we are forced to work with a cross section. Our estimation strategy is as follows. We first estimate a translog function (Christensen and Jorgenson, 1969) and test on the validity of the Cobb-Douglas restriction. Since the latter passes the test, we focus on it and tackle the simultaneity problem to obtain reliable estimates of the output elasticities. Finally, having found a marginal product of ICT capital high than its user cost, we try to speculate on possible barriers to investment.

The translog specification of (1) takes on the following form

$$
\begin{aligned}
(3) \qquad y_i \; = \; & \beta_0 + \beta_1 k_i^{OTH} + \beta_2 k_i^{ICT} + \beta_3 l_i + \beta_4 S_i + \beta_5 l_i^2 + \beta_6 \left(k_i^{ICT}\right)^2 + \\
& + \beta_7 \left(k_i^{OTH}\right)^2 + \beta_8 S_i^2 + \beta_9 \left(l_i \cdot k_i^{ICT}\right) + \beta_{10} \left(l_i \cdot k_i^{OTH}\right) + \\
& + \beta_{11} \left(k_i^{ICT} \cdot k_i^{OTH}\right) + \beta_{12} \left(k_i^{ICT} \cdot S_i\right) + \beta_{13} \left(k_i^{OTH} \cdot S_i\right) + \beta_{14} \left(l_i \cdot S_i\right) \\
& + a_i + \varepsilon_i,
\end{aligned}
$$

where lowercase letters indicate logarithms. To proxy for unobserved firm-level productivity we use a set of controls to capture unobserved technology level and managerial preferences. In particular, we use dummies for sector, location and ownership structure. To account for unobserved R&D capital stock, we add the share of R&D employees. We always use heteroskedasticity-robust standard errors. On the basis of this estimation, since the test $\beta_5 = ... = \beta_{14} = 0$ is not rejected, with $F(10, 1742) = 1.64$ ($Prob > F = 0.09$), in what follows we use a simple Cobb-Douglas specification (in logs):

$$
(4) \qquad y_i = \beta_0 + \beta_1 k_i^{OTH} + \beta_2 k_i^{ICT} + \beta_3 l_i + \beta_4 S_i + a_i + \epsilon_i.
$$

The basic regression results are presented in column 1 of Table 5. Estimated elasticity are very close to income shares: labor elasticity is 0.7 and the aggregate capital one close to

0.3; the coefficient of schooling is significant and amounts to 3.2 per cent[15]. There is also clear evidence in favor of constant returns to scale ($F(1, 1752) = 2.08$ with $Prob > F = 0.15$).

ICT capital enters as a productive input and its elasticity is above 6 per cent. This estimate is slightly higher than both the corresponding estimates in Brynjolfsson and Hitt (1995) (around 5 per cent), who use an ICT measure that mixes computers and information systems staff labor and than that in Bresnahan *et al.* (2001) (around 3.5 per cent), which reflects an ICT capital stock definition that excludes software. Our relatively high estimate for ICT could capture the skill composition of the labor force; as already stated, failing to account for it may lead to overestimate the return to ICT, since it would be partially measuring the effect of the greater share of white collar. The results of splitting, in equation (4), labor input between white and blue collar[16] are reported in column [2]: the estimate of the output elasticity to ICT is indeed lowered to slightly above 4 per cent, but it is still significantly estimated. Also the return to schooling is smaller (1.8 per cent).

Indeed, our regressions are not immune to the problems usually encountered in estimating production functions: as neatly pointed out by Griliches and Mairesse (1998), our results may be subject to the simultaneity/omitted variable bias due to unobserved firm characteristics. This problem originates because it is not possible to treat right hand side variables as independent, since inputs are simultaneously chosen — either optimally or in a behavioral fashion — by the producers who are supposed to know their (unobservable) productivity. In this case the usual exogeneity assumptions required for consistency of OLS do not hold. In fact, we cannot control for all firm specific effects: in the empirical literature the most used way to remove time-invariant firm-specific effects is to estimate in first differences, a strategy clearly precluded to us. Moreover, since inputs are chosen on the ground of firm belief about productivity, if the latter is serially correlated, inputs will be positively correlated with it and OLS will provide upwardly biased estimates of the input coefficient.

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15 This estimate is reasonably close to what reported by Psacharopulos (1994) for Italy. Using the measure of average years of schooling that weights different workers by a measure of their market wage, as described in Brandolini and Cipollone (2001), does not change the results.

16 By doing this, we loose 13 observations.

To verify the impact of these problems on our estimates we follow Olley and Pakes (1996). In particular we replicate their stage one and assume that investment is a function of unobserved productivity (a) and of all the fixed inputs (vector $\mathbf{z}_i$) in production that is

$$inv_i = f(a_i, \mathbf{z}_i). \quad (5)$$

If this function is strictly increasing in a it can be inverted to give

$$a_i = g(inv_i, \mathbf{z}_i). \quad (6)$$

This means that we can express the unobserved productivity variable as a function of observables. Therefore, to account for the possible correlation of right hand side variables with unobserved firm-level effect not otherwise captured by our controls, we include in the regression the logarithm of investment (column [3]). This amounts to proxy unobserved productivity with a linear function of investment and the fixed factors. The noteworthy results of this regression are that the investment coefficient is positive but insignificant ($t-statistic = 1.2$) and that the coefficients of *all* other inputs are almost literally unchanged. In particular, the labor input coefficients — blue and white collar — are respectively 0.341 and 0.375, instead of 0.345 and 0.374 (column [2]). This supports the idea that in Italy labor can be considered as a fixed factor. Similarly, the other capital coefficient changes very little, from 0.240 to 0.236. The largest change (more than 8 per cent) relates to ICT, whose coefficient drops from 0.041 to 0.0376. This seems to imply that if there is any variable input, whose estimated coefficient is correlated with unobserved productivity, this is ICT capital. Still, if this conclusion is correct, it should survive with a specification of the unobserved productivity less constraining than the linear just used.

Therefore, let us assume for the moment that ICT capital is the only variable input and specify unobserved productivity with a quadratic polynomial in investment and the other inputs[17]. In this case (column [4]) the coefficients of these latter variables have no direct interpretation since they confound the effect of fixed inputs on output with their effect on

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[17] In particular, beside the level of investment, we use also squared terms for investment,other capital stock, blue and white collar and all cross products.

productivity, while the coefficient of the supposed variable input should be identified. To our relief, the coefficient of ICT capital is again estimated at 0.041, the same value as in the basic specification of column [2]. This allow us to conclude that there not seem to be correlation between inputs and unobserved productivity and, therefore, that estimates in column [2] are unbiased.

Under perfect competition and constant returns to scale estimated input coefficients should equal their income share. In our preferred specification (column [2] of Table 5) ICT capital is a productive input whose elasticity is around 4 per cent. But what does this imply for the marginal product of ICT capital? Evaluated at the median of the sample distribution of $\frac{K^{ICT}}{Y}$, installing 100 more Liras of ICT capital yields 80 more Liras of output[18]. If we compare this value with the user cost of ICT capital ($r + \delta - \dot{p}$, the Jorgensonian rental price), which roughly amounts to 46 per cent[19], we find a very large excess return.

As suggested by Brynjolfsson and Hitt (2000), this excess return might mask unmeasured barriers to investment. The point is that if there are constraint to ICT investment, ICT capital stock will be low and, given diminishing returns, its marginal product will be high. In what follows we test whether taking into account the constraints posed by possible barriers helps to reconcile the extremely high marginal return to ICT capital with its lower user cost. Our approach consists in separating "constrained" from "unconstrained" firms and evaluate their respective marginal products. If our presumption is correct, "unconstrained" should display a lower marginal product of ICT capital.

For their strong complementarity with ICT, two candidate barriers to investment are the availability of skilled workers and the ability to reorganize the production process towards the so called "best-work practices" (Bresnahan *et al.*, 2000). If this hypothesis is true, the "constrained" firms — that is those that did not reorganize and/or those that did not invest in human capital — should display marginal products of ICT higher than "unconstrained" firms.

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18 The sample distribution of $\frac{K^{ICT}}{Y}$ has a median of 5.1 per cent and a mean of 8.3 per cent: since the capital stock for the entire manufacturing ranges between 4.9 and 5.4 per cent of value added (see Table 4) we use the median of the sample distribution to calculate the implied marginal product of ICT capital.

19 We use the prime rate to measure r (9.2 per cent in 1997). The depreciation rate δ is the simple average of the annual depreciations of hardware, software and telecommunication equipment. To proxy the expected price change $\dot{p}$ we use a simple average of price changes (in Liras) in the last three years as in Daveri (2000). For the US, Brynjolfsson and Hitt (2000) report a user cost of computer capital of 42 per cent.

It is worth mentioning that having a larger $\frac{K^{ICT}}{Y}$, as unconstrained firms do, is not a sufficient condition for a lower marginal product, since the estimated elasticity may also change. A critique to this approach might be that we are splitting the sample according to endogenous variables. We believe that this is not the case since, on one side, the reorganization dummy refers to the triennium 1995-97, while output and inputs are as of 1997. On the other side, average years of schooling of the workforce — our measure of human capital — is a very sticky variable, especially in Italy, where, as shown before, labor can be considered a fixed input in production.

To test this hypothesis, in column [1] of Table 6 we let the ICT coefficient of firms that performed a reorganization associated to a process innovation in the past three years to differ from that of firms that did not. The point estimates of the two ICT coefficients are identical, but given that firms that did not reorganize (the "constrained") display also a lower ICT capital on value added ratio, their implied marginal product of ICT (evaluated at the median) — reported in curly brackets below the standard error — is higher than that of firms that reorganized, respectively 86 vs. 70 per cent. In column [2] we perform the same exercise but let constrained firms to be those that had labor force average human capital below the median (10 years, 878 firms): if the barriers to investment story is true these should also display a marginal product of ICT higher than that of firms with average human capital of the workforce above the median. Indeed, the point estimate of the ICT capital coefficient is 0.043 for the constrained and 0.039 for the unconstrained. Combined with a lower $\frac{K^{ICT}}{Y}$, ICT marginal return for constrained firms jumps to 97 per cent against a much smaller one for the unconstrained (67 per cent). Finally, in column [4] we define as "constrained" the firms that both did not reorganize and had average human capital below the median (570 observations), "unconstrained" those that both reorganized and had average human capital above the median (217 observations) and "intermediate" all remaining ones, that is firms that either invested above the median in human capital but not reorganized or the other way round (983 observations). Point estimates of ICT coefficient are lowest for the unconstrained (approximately 0.036) and highest for the intermediate (0.044). The ranking of marginal products is as expected: for unconstrained firms the marginal product of ICT is much lower than both intermediate and constrained firms. More importantly, the marginal product of ICT for unconstrained firms drops to 47.2 per cent, practically the same value as the user cost of ICT capital as measured by the rental price (45.8 per cent). Furthermore, it is interesting to notice that both constrained and intermediate firms display similar marginal products, signalling that both reorganization of production process and investment in human capital are essential for investment in ICT.

Overall, these results support the idea that the excess return to ICT is due to some form of barriers to investment. Among these both low human capital of the labor force and impossibility to reorganize the production process seem to play a relevant role.

6. Concluding remarks

In this paper we have analyzed the depth of the “new economy” in Italy by examining the diffusion of ICT among manufacturing firms.

According to various case studies and a few empirical papers on US data, the adoption of ICT requires skilled labor and firm reorganization. We found support to this hypothesis. In particular, the decision to adopt ICT is positively correlated with the reorganization of production process, while the scale of investment is also positively correlated with the level of human capital in the workforce.

From a sample of about 2,400 firms, we then computed a measure of the total ICT capital stock and found in the Italian manufacturing a substantial delay with respect to the US, of approximately 8 years.

Such measure enabled us to estimate a production function. We obtained an elasticity of value added to ICT capital close to 4 per cent. It implies a marginal product of ICT capital much higher than its the user cost. Our hypothesis is that this is due to possible barriers to investment in ICT: given the high complementarity, confirmed by partial correlations in Section 3, firms that find it difficult to augment the skill level of their labor force and to change workplace organization do not invest in these technologies. In fact, selecting out firms that reorganized the production process and have a relatively high average human capital we can (fully) explain such excess returns. Furthermore, firms that invested in only one of these complementary inputs (*i.e.* either in human capital or in reorganization) do not appear — in terms of excess return — very different from firms that invested in neither of the above. This suggest that both a sufficiently high skill level of the labor force and a reorganization of firm activity are essential for ICT investment.

Appendices

A.1 **Data sources**

A.1.1 *The CADS data set*

Firms are drawn from the archives of the Italian Company Accounts Data Service. The data, available from 1982 to 1998, cover balance sheet information and other items on over 30,000 Italian firms. Centrale dei Bilanci is the organization in charge of gathering and managing the data. Centrale dei Bilanci has been established in the early ’80s jointly by the Bank of Italy, the Italian Banking Association (ABI) and a pool of leading banks. The goal is to collect and share information on borrowers. Balance sheets are reclassified in order to reduce the dependence on accounting conventions used by each firm to record income figures and asset values. Other information regards firm demographics, employment and flow of funds. The focus on the level of borrowing skews the sample toward larger firms and as a consequence toward Northern firms. Moreover, since banks deal mainly with firms that are creditworthy, the sample is also biased toward better than average quality borrowers.

A.1.2 *The SMF dataset*

The SMF is conducted by the Observatory on small and medium size firms hosted within the Research Department of the Mediocredito Centrale. A Committee comprised of academics and public officials acts as a supervisor. The survey was for the first time put in place in 1968. Then it has been repeated more or less every five year until 1989; afterwards, this interval has been reduced to three years. The last three versions of the survey, covering the periods 1989-1991, 1992-94 and 1995-97, share a similar structure. In all the cases, the SMF samples firms with 11 to 500 employees, while it collects information on all the firms with more than 500 employees.

Restricting to the last release (1995-97), the sample has been stratified according to number of employees and location, taking as benchmark the 1996 Census of Italian Firms. Besides balance sheet information, SMF provides a wide range of qualitative and quantitative information on various aspects of firm’s activity. There are six sections. The first refers to demographics information, interestingly detailed on ownership structure: firms have been asked for the typology of persons or company controlling the firm, for the characteristics of the group the firm might belong to. Then there is a section on labor force containing information on the distribution of employees in terms of skills and education; other information relates to the recent hiring and training policies. Section 3 provides a rich set of data on investment and R&D: here firms are also asked about their ICT investment over the triennium. Market structure and internationalization strategies are thoroughly analyzed in section 4 and 5. Finally, section 6 focuses on financial aspects.

A.2 **Data details**

A.2.1 *Capital Stock*

We used data from the Company Accounts Data Service (CADS), supplemented with data from Mediocredito Centrale (SMF) where these were not available.

Total Capital Stock, at 1997 prices, was computed by applying the method used by BBH (2001). The formula used to compute the capital stock is the following

$$K_t^{tot} = \frac{BV_t \left(1 - \delta\right)^{age_t}}{P\left(age_t\right)} \tag{A.2.1}$$

where BV is total gross book value of capital (sum of *immobilizzazioni materiali lorde* and *immobilizzazioni immateriali*, the gross value of *immobilizzazioni immateriali* was calculated as the sum of the net value and the three-year cumulated depreciation of the same item); δ is the average depreciation rate of the sector to which the firm belongs (from ISTAT); P is the price deflator of fixed investment in the sector to which the firm belongs (from ISTAT); age is the age of the capital stock calculated as the minimum between the age of the firm and the three-year average of the ratio between total cumulated depreciation to current depreciation, that is

$$age_t = \min\left(t - t_0, \quad \frac{1}{3}\frac{\sum_{i=0}^{t_0} \delta_{t-i}^K}{\delta_t^K} + \frac{1}{3}\frac{\sum_{i=0}^{t_0} \delta_{t-1-i}^K}{\delta_{t-1}^K} + \frac{1}{3}\frac{\sum_{i=0}^{t_0} \delta_{t-2-i}^K}{\delta_{t-2}^K} \right) \tag{A.2.2}$$

where t_0 is the year of foundation and δ^K is total depreciation (sum of *ammortamenti materiali* and *ammortamenti immateriali*).

A.2.2 *ICT Capital Stock*

The ICT capital was constructed from the value of total investment in ICT in the three-year-period 1995-97 (from SMF) using the following five-step methodology:

A. For the triennium, we derive the value of investment in hardware, software and telecommunication equipment by applying the correspondent shares, available in SMF, to the total ICT figure. For those firms that did not provide such shares, we use the average ones: over total investment in ICT, 53.7 per cent is in hardware, 41.9 in software, 4.4 in telecommunication equipment. As a result, we get:

$$inv^{har}_{95-97} = sh^{har}_{95-97} \cdot inv^{ICT}_{95-97}, \qquad (A.2.3)$$

$$inv^{sof}_{95-97} = sh^{sof}_{95-97} \cdot inv^{ICT}_{95-97}, \qquad (A.2.4)$$

$$inv^{tel}_{95-97} = sh^{tel}_{95-97} \cdot inv^{ICT}_{95-97}, \qquad (A.2.5)$$

B. We derive yearly figures inv^{j}_{1997-i}, where $i = 0, 1, 2$ and $j = har, sof, tel$. For this, we use the dynamics of Italian nominal imports of hardware, software and telecommunication equipment under the constraint that the sum of the three years equals the primitive figure for the triennium. Import data come from OECD for computers (category 752: *Automatic data processing machines, n.e.s.*) and telecommunication equipment (category 764: *Telecommunication equipment, n.e.s.; and parts, n.e.s.*), and ISTAT for software (category KK72: *Prodotti informatici*). Since the former two are in dollars, we convert them in liras through the annual average of the monthly average exchange rate between liras and dollars. In applying import growth rates, we control and fix two specific cases: i) for those firms with inv^{ICT}_{95-97} equal to nominal total investment in machinery and equipment (inv^{TOT}_{95-97}), we set $inv^{ICT}_{1997-i} = inv^{TOT}_{1997-i}$(available in SMF); we then apply to inv^{ICT}_{1997-i} the shares, as in step 1, ; ii) for those firms claiming zero investment in machinery and equipment for one (two) year, we set the correspondent ICT investment to zero; then import growth rates are used to spread the ICT figures for the triennium over the other two (one) years; shares are then used to split total yearly figure in hardware, software and telecommunications.

C. We project backwards the nominal figures, according, again, to the dynamics of imports of hardware, software and telecommunication equipment. We follow the information on the service lives of these goods provided by Fraumeni (1997) and Seskin (1999) and construct data for hardware since 1991, for software since 1994 and for telecommunications since 1987. It is worth mentioning that the 1994 figures are obtained using the ratio between imports over the triennium 1995-97 and imports for 1994: this is to make use of our primitive information on firms' investment in ICT instead of our artificial yearly figures. Therefore we have inv^j_{1997-i} where now $i \in \{0, 1, ..., 6\}$ for $j = har$, $i \in \{0, 1, 2, 3\}$ for $j = sof$, $i \in \{0, 1, ..., 10\}$ for $j = tel$.

D. We transform nominal investments into real net values, evaluated at 1997 prices and exchange rate:

$$rinv^j_{1997-i} = \frac{inv^j_{1997-i}(1-\delta^j)^i}{P^j_{1997-i}}, \tag{A.2.6}$$

where δ^j is the constant annual depreciation rate of asset j and

$$\begin{aligned} P^j_{1997-i} &= 100, & i = 0 \\ P^j_{1997-i} &= \frac{P^j_{1997-i+1}}{1+\left(\frac{P^{j,US}_{1997-i+1}}{P^{j,US}_{1997-i}}-1\right)+\left(\frac{e_{1997-i+1}}{e_{1997-i}}-1\right)}, & i > 0 \end{aligned} \tag{A.2.7}$$

where $p^{j,US}$is the US hedonic price index for private fixed investment in asset j and e is the Italian lira/US dollar exchange rate.

E. Finally, we sum up real investment in ICT by component and across time to obtain the ICT capital stock:

$$K^{ict}_{1997} = \sum_{i=0}^{3} rinv^{sof}_{1997-i} + \sum_{i=0}^{6} rinv^{har}_{1997-i} + \sum_{i=0}^{10} rinv^{tel}_{1997-i} \tag{A.2.8}$$

A.2.3 *"Other" capital stock*

The capital stock different from ICT is computed residually. We first derive ICT capital stock in nominal terms and net of depreciation:

$$\left(\sum_{i=0}^{3} inv^{sof}_{1997-i}(1-\delta^j)^i + \sum_{i=0}^{6} inv^{har}_{1997-i}(1-\delta^j)^i + \sum_{i=0}^{10} inv^{tel}_{1997-i}\,(1-\delta^j)^i\right) \tag{A.2.9}$$

We then subtract it from the equivalent measure for the total capital stock:

$$BV_t\,(1-\delta)^{age_t} \tag{A.2.10}$$

Finally, we transform the resulting nominal figure into a real one using, as for the total capital stock, the price deflator of fixed investment provided by ISTAT. This does not entail a too big distortion since such deflators imply no corrections for quality at all. In absence of additional information, we assume the other capital has the same average age of the total capital.

A.2.4 *Human capital*

We construct a firm-level measure of human capital using information on workers education. For this, we attribute 18 years of schooling to workers with a college ("laurea") degree (L^{col}), 13 to those with high school (L^{hsc}), 8 to those with none or only compulsory education (L^{lsc}). That is

$$S = \frac{18L^{col} + 13L^{hsc} + 8L^{lsc}}{L} \tag{A.2.11}$$

where L is the total workforce.

A.2.5 *Reorganization*

The question asked in the SMF concerning reorganization is the following:

In the triennium 1995-97, the firm realized (multiple answers admitted):

[] *organizational innovations related to product innovations*

[] *organizational innovations related to process innovations*

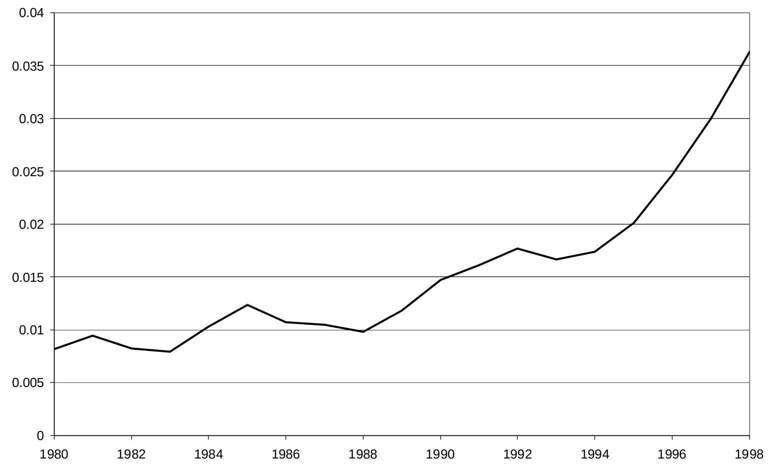
[] *organizational innovations related to both product and process innovations*

We build three dummies: the first is 1 if the firm answered positively to any of these questions, the second is 1 if the firm realized a reorganization related only to process innovations, the third is 1 if the firm realized a reorganization related only to product innovations.

Tables and figures

Figure 1

US manufacturing: inv(ICT)/y



US manufacturing: k(ICT)/y

Source: BLS.

Notes: inv(ICT) is investment in hardware, software and communication equipment; k(ICT) is capital stock of hardware, software and communication equipment; y is value added. Both numerators and denominators are in constant 1996 US dollars.

Table 1

Descriptive statistics: sample means (1997)

	Full sample	Zero ICT
value added (millions of liras)	16,398	6,258
employees	158	74
white collars	53	20
blue collar	105	54
employment in R&D	0.02	0.01
average years of schooling	10.3	10.2
firm age	25	22
group membership (0,1)	0.30	0.21
public property (0,1)	0.01	0.01
reorganization: either product or process (0,1)	0.30	0.16
reorganization: product (0,1)	0.15	0.06
reorganization: process (0,1)	0.26	0.13
capital stock/value added	2.06	2.12
cash flow/total assets (1995-97 average), median	0.08	0.07

Table 2

Descriptive statistics: sector and location, sample means

(percentages; 1997)

	Full sample	Zero ICT
Food, beverages and tobacco	10.1	13.9
Textile	10.7	10.1
Apparel and related products	2.0	2.0
Leather and leather products	3.5	6.6
Lumber and wood products	3.1	2.7
Paper and allied products	3.7	3.3
Printing and publishing	2.4	1.3
Petroleum refining and related industries	0.3	0.2
Chemicals and allied products	4.9	6.0
Rubber and plastic products	6.5	6.8
Stone, clay, glass	6.6	9.3
Primary metal products	6.5	5.6
Fabricated metal products	7.0	6.0
Industrial and commercial machinery	17.5	11.2
Computer and office equipment	0.4	0.2
Electrical equipment	3.1	2.7
Audio, video and communication equipment	1.7	2.4
Measuring and controlling instruments	1.6	1.5
Motor vehicles	2.7	1.5
Other transportation equipment	1.0	0.9
Furniture, fixture and miscellaneous manufacturing	4.7	5.7
Total	100	100
North West	41.3	29.5
North East	29.6	31.1
Center	16.9	23.6
South	12.2	15.7

ICT investment

	[1]	[2]	[3]
	OLS (full sample)	Probit (marginal effects) (full sample)	OLS (subsample)
Human capital	0.165	0.000	0.212
	(0.073)	(0.007)	(0.094)
D_org	0.682	0.139	0.347
	(0.206)	(0.017)	(0.233)
Sales per employee	0.087	0.000	0.091
	0.032	(0.001)	(0.035)
% white collar	0.049	0.002	0.052
	(0.009)	(0.001)	(0.010)
D_group	0.587	0.064	0.465
	(0.241)	(0.019)	(0.287)
D_pub	-1.532	-0.003	-1.782
	(0.448)	(0.091)	(0.509)
$D\_sector(Prob > F)$	0.000	0.001	0.000
$D\_area\ (Prob > F)$	0.976	0.000	0.586
No. obs	2397	2397	1851
Prob $>$ F (or χ^2)	0.000	0.000	0.000
R^2	0.095	0.075	0.094
Predicted probability	-	0.793	-

Notes: OLS and Probit estimates (marginal effects), heteroskedasticity-robust standard error in parentheses; the dependent variable is nominal ICT investment per employee; human capital is the average years of schooling, D_org is a dummy 1 for firms that performed some process reorganization, D_group is a dummy 1 for firms that belong to a group, D_pub is a dummy 1 for firms controlled by the Government, D_sect is a set of dummies 1 for each Nace Rev. 1 industry, D_area is a set of dummies 1 for location (north-west, north-east, center, south). For further details see the Appendix.

ICT investment and capital stock

(percentage of value added, by sector; 1997)

	Investment		Capital stock	
	full sample	positive ICT	full sample	positive ICT
Food, beverages and tobacco	2.4	2.6	5.4	6.0
Textile	2.5	2.7	5.6	6.2
Apparel and related products	2.1	2.1	4.6	4.7
Leather and leather products	1.7	2.6	3.8	5.8
Lumber and wood products	2.6	3.2	6.1	7.4
Paper and allied products	1.9	2.2	4.2	4.9
Printing and publishing	4.8	4.8	11.0	11.2
Petroleum refining and rel. ind.	1.2	1.2	2.6	2.6
Chemicals and allied products	2.9	3.1	6.5	7.1
Rubber and plastic products	3.8	4.5	8.5	10.2
Stone, clay, glass	2.2	2.4	4.7	5.1
Primary metal products	1.8	1.9	4.0	4.4
Fabricated metal products	3.3	3.6	7.4	8.3
Industrial and commercial mach.	3.3	3.4	7.7	7.9
Computer and office equipment	4.9	5.0	12.3	12.5
Electrical equipment	2.5	2.6	5.7	6.0
Audio, video and comm. equip.	2.3	2.7	5.3	6.2
Measuring and controlling instr.	4.6	5.2	10.8	12.2
Motor vehicles	3.1	3.2	7.2	7.5
Other transportation equipment	4.1	5.7	9.7	13.4
Furniture and other manuf.	2.9	2.9	6.6	6.6
Total	2.2	2.4	4.9	5.4

Production function: basic specification

	[1]	[2]	[3]	[4]
	basic	white/blue	Olley-Pakes	
ICT capital	0.062	0.041	0.038	0.041
	(0.009)	(0.011)	(0.011)	(0.010)
Other capital	0.224	0.240	0.236	-0.306
	(0.016)	(0.016)	(0.016)	(0.203)
Labor	0.700	-	-	-
	(0.023)			
White collar	-	0.374	0.375	0.990
		(0.024)	(0.024)	(0.229)
Blue collar	-	0.345	0.341	0.420
		(0.019)	(0.019)	(0.197)
Human capital	0.032	0.018	0.018	0.010
	(0.008)	(0.008)	(0.008)	(0.008)
R&D employment	0.368	0.337	0.325	0.168
	(0.153)	(0.161)	(0.161)	(0.154)
D_group	0.124	0.101	0.103	0.080
	(0.027)	(0.027)	(0.028)	(0.026)
D_pub	0.045	0.019	0.018	0.030
	(0.099)	(0.093)	(0.093)	(0.095)
Investment	-	-	0.010	0.017
			(0.008)	(0.101)
Other variables	-	-	-	Polynomial in other inputs
$D\_sector\ (Prob > F)$	0.000	0.000	0.000	0.000
$D\_area\ (Prob > F)$	0.000	0.000	0.000	0.000
No. obs	1783	1770	1770	1770
Prob>F	0.000	0.000	0.000	0.000
$\bar{R}^2$	0.921	0.920	0.920	0.927

Notes: OLS estimates, heteroskedasticity-robust standard error in parentheses; the dependent variable is the logarithm of value added; all explanatory variables except human capital are logarithms; capital stock other than ICT is weighted by the index f capacity utilization; human capital is the average years of schooling, D_group is a dummy 1 for firms that belong to a group, D_pub is a dummy 1 for firms controlled by the Government, D_sect is a set of dummies 1 for each Nace Rev. 1 industry, D_area is a set of dummies 1 for location (north-west, north-east, center, south). See the text for details about the Polynomial in column [3]. For further details see the Appendix.

Production function: barriers to investment

	[1]	[2]	[3]
	Reorganization	Human capital	Reorg./Hum. cap.
ICT capital	0.041	0.043	0.040
(constrained)	(0.011)	(0.011)	(0.011)
	{85.6}	{97.3}	{91.6}
ICT capital	-	-	0.044
(intermediate)			(0.011)
			{85.7}
ICT capital	0.041	0.039	0.036
(unconstrained)	(0.011)	(0.012)	(0.012)
	{70.2}	{66.5}	{47.3}
Other capital	0.240	0.240	0.240
	(0.015)	(0.015)	(0.016)
White collar	0.374	0.375	0.375
	(0.024)	(0.024)	(0.024)
Blue collar	0.345	0.345	0.344
	(0.019)	(0.019)	(0.019)
Human capital	0.018	0.025	0.018
	(0.008)	(0.012)	(0.009)
R&D employment	0.338	0.330	0.362
	(0.164)	(0.162)	(0.163)
D_group	0.101	0.101	0.102
	(0.027)	(0.027)	(0.027)
D_pub	0.019	0.019	0.017
	(0.093)	(0.093)	(0.091)
$D\_sector\ (Prob > F)$	0.000	0.000	0.000
$D\_area\ (Prob > F)$	0.000	0.000	0.000
No. obs	1770	1770	1770
Prob>F	0.000	0.000	0.000
$\bar{R}^2$	0.920	0.920	0.920

Notes: OLS estimates, heteroskedasticity-robust standard error in parentheses; the dependent variable is the logarithm of value added; all explanatory variables are the same as in Table 5. In columns [1] "unconstrained" refers to firms that conducted a reorganization associated with a process innovation, "constrained" to those that did not. In column [2] "unconstrained" refers to firms that have human capital above the median, "constrained" to those below. In columns [3] "unconstrained" refers to firms that both conducted a reorganization associated with a process innovation and that have human capital above the median, "constrained" to those that both did not reorganize and have human capital below the median, "intermediate" are all the others.

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