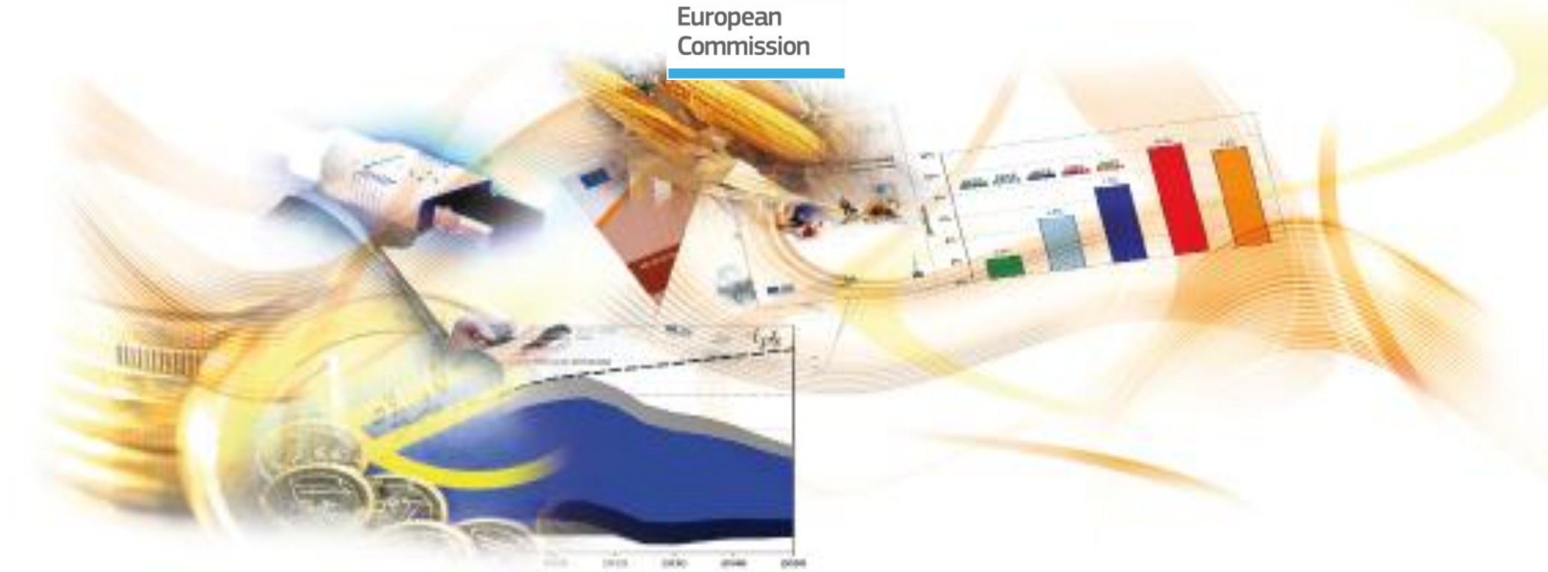
European Commission



JRC TECHNICAL REPORTS

Are ICT, Human Capital and Organizational Capital Complementary in Production? Evidence from Italian Panel Data

Federico Biagi
Maria Laura Parisi

2012

Report EUR 25542 EN

Joint Research Centre

European Commission
Joint Research Centre
Institute for Prospective Technological Studies

Contact information
Address: Edificio Expo. c/ Inca Garcilaso, 3. E-41092 Seville (Spain)
E-mail: jrc-ipts-secretariat@ec.europa.eu
Tel.: +34 954488318
Fax: +34 954488300

http://ipts.jrc.ec.europa.eu
http://www.jrc.ec.europa.eu

This publication is a Technical Report by the Joint Research Centre of the European Commission.

JRC75890

EUR 25542 EN

ISBN 978-92-79-26921-9

ISSN 1831-9424

doi:10.2791/99567

Luxembourg: Publications Office of the European Union, 2012

Printed in Spain

Acknowledgements

We would like to thank the Italian Ministry for Education, University and Research (MIUR) and SDA Bocconi Business School for financial support.

Preface

This report investigates the effect of ICT and complementary assets - organizational change and human capital- on the labour productivity of Italian manufacturing firms.

Given its focus, this report is relevant both for the Innovation Policies and the Digital Agenda research lines carried out by the Information Society (IS) Unit at JRC-IPTS in the context of the IDEA Action during the last couple of years. For both research lines, the issue of how ICT could complement organizational change (which is one type of innovative behaviour) and human capital and hence impact on productivity are fundamental issues. In fact, a whole line of research has emerged in the last 10-15 years on the role of ICT as a General Purpose Technology, i.e. a driver of co-inventions or co-innovations (organizational change being one of them, as ICT make new management practices possible and profitable.)

The results of this report, which is based on data from Italian manufacturing firms, show that, within this sector, there is no evidence of complementarity between ICT investment and organizational change. This for us is only partially a surprise as in other studies (using Dutch data) it has been recently found that the complementarity between ICT and organizational change is much lower in the manufacturing sector than in the service sector. Future research, conducted at the IS Unit of JRC-IPTS, will look at the actual usage of ICT (ERP, CRM, broadband penetration) in the context of different business models and its impact on firms' productivity.

Table of Contents

1. Introduction

Information and communication technologies (ICT) have drastically changed society over the last 25 years, inducing unexpected qualitative and quantitative changes. Engineers, economists, sociologists and, in general, media experts and commentators have debated the effects of the ICT revolution on our lives. However, the empirical literature raised a puzzling concern, that while investment in ICT during the eighties and early 90s was growing exponentially in the U.S. and quality-indexed prices for computers were rapidly (and exponentially) falling, productivity in the service industry, accounting for approximately 80% of IT investment, was actually stagnating. This concern was well expressed by the famous sentence of Robert Solow (1987): "*You can see the computer age everywhere but in the productivity statistics*" (the Solow paradox or productivity paradox[1]).

There are several reasons why the effects of the IT revolution on growth were not fully visible by the mid 1990's. First, accurate quantitative measures for the output and value created by IT are difficult to obtain. Measuring the value of IT capital is per se a very difficult task, which depends on the depreciation rates we use. Similarly, assessing the impact of IT on productivity is complex if productivity cannot be properly measured, as is often the case in the service sector. These problems are exacerbated when macro data are used.

Second, the effect of the IT revolution on GDP growth is proportional to the IT capital stock existing in an economy. So, even fast technological progress in the IT sector cannot have a major effect on the overall economic performance if the IT capital value is low relative to other capital values. Finally, if IT creates value that is not easily measurable (like intangible capital) we run the risk of apportioning to TFP an effect on growth that is due to IT and to its complementary inputs.

For these reasons, the empirical literature on the impact of IT on growth has opted for sector or firm-level data, since only at a very disaggregated level –and possibly in longitudinal form- can we hope to capture evidence of the multifaceted improvements

---

1 On the productivity paradox, see for example Lee et al. (1999) Strassmann (1990), Loveman (1990), Barua *et al.* (1991), Morrison and Berndt (1990), Roach (1989) and Panko (1991).

that IT can provide and take into account the possibility of firm or plant-specific fixed effects (due, for instance, to the presence of a particular management style).

Probably, the most influential empirical micro-literature looks at the role of ICT and complementary assets in the determination of firms' productivity. This interest arises primarily from the double nature of ICT: it favours process/product innovation and it is an enabler of organisational change. Concerning the first point, being a general purpose technology, ICT is embedded in many manufacturing products and services, and it gives rise to a process of co-invention. Moreover, ICT is an enabler of organizational change: it leads to a redefinition of strategies, processes and practices with clear results on the operational and innovation capabilities of firms. In fact, in the last 15 years, a strand of economic literature has studied the joint impact of organizational change and ICT investment on labour productivity.[2] The basic intuition of this literature is that ICT investment, per se, is not likely to have a huge impact on firms' productivity. This impact can be obtained when investment in ICT is complemented with investments in other assets. First, capital goods that embed digital technology are often substituted for unskilled labour in routine jobs but they complement labour in complex and cognitively demanding jobs (mostly managerial): this implies that ICT investment is complementary to human capital investment (i.e. ICT productivity raises with the level of human capital in the firm). Second, ICT are considered to be complementary to organizational capital: ICT capital becomes productive when firms have an organizational and managerial structure that really benefits from ICT adoption.[3]

In this report, we explore the issue of ICT, organizational capital and human capital complementarities in determining firm's productivity, using firm-level data coming from

[2] This literature is actually the result of the intersection between different strands. On the one hand we have the literature on the effect of work-practices on productivity and wage inequality, while on the other, we have the literature that studies the impact of ICT-induced changes on firms' organizational structure and productivity.

[3] When managers are asked to name and possibly rank the benefits coming from computerization they indicate the following: increases product differentiation, better supply chain management, improved product quality, better producer-customer relationship. These factors that are very likely to go unmeasured by standard price deflators but they are a clear representation of the effects of a GPT: it enables complementary innovations. It is exactly the role and the relevance of such complementary innovation that lead Brynjolfsson and Hitt (2000) to conclude that "*a significant component of the value of information technology is its ability to enable complementary organizational investments such as business processes and work practices;…these investments, in turn, lead to productivity increases by reducing costs and, more importantly, by enabling firms to increase output quality in the forms of new products or in improvements in intangible aspects of existing products like convenience, timeliness, quality, and variety*".

the Italian "*Indagine sulle Imprese Manufatturiere*" (Capitalia-Unicredit), for the period 1995-2003. This is a crucial period for the evolution of the Italian manufacturing productivity performance, and for Europe overall, as it was from 1995 that the IT revolution blossomed in the US, producing an acceleration in rates of productivity growth that was not observed in Europe. Understanding what went wrong in these years is important to understanding Italy's overall productivity slowdown during the past 15 years.

The report is structured as follows: Section 2 reviews by and large the literature on ICT investment and productivity growth, Section 3 describes briefly the data, Section 4 illustrates the econometric framework and presents the results, and Section 5 offers conclusions.

2. ICT, organizational change and human capital in the literature

As Brynjolfsson writes, there are *"two central questions which comprise the productivity paradox: 1) Why would companies invest so heavily in information technology if it didn't add to productivity; 2) If information technology is contributing to productivity, why is it so difficult to measure it?"*.

One possible answer to the second question is that: a) many of the benefits from computerization are hard to measure and they are often indirect effects;[4] b) ICT become productive only when coupled with investment in complementary assets: organizational and human capital.

The implications of the complementarity hypothesis (which goes back to Milgrom and Roberts, 1990) are that: 1) ICT investment, per se, might have a very low positive impact on productivity (in fact the impact could even be negative); 2) the impact of ICT investment becomes largely positive once it is coupled with organizational change (which, per se, might have a smaller positive impact); 3) due to the complementarity between ICT investment and organizational change, we should expect some lag between the time we record the investment in ICT and the time we observe the positive impact on productivity and this time-lag is entirely due to the organizational change that the firm has to go through if it wants to reap the full benefit of ICT investment; 4) the distribution of skills among the workforce and the level of human capital are important in determining the impact of ICT investment and organizational change; 5) not all firms could benefit in the same way from ICT investment since not all firms (and not all sectors) are able to implement successful organizational change.

The complementarity hypothesis[5] and the derived corollaries are important because they provide: a) an explanation for the Solow's paradox: it takes time to observe the benefits from computerization; b) an explanation for the large increase in productivity observed in the US in the second half of the 90s (especially in ICT using sectors); c) an interesting

[4] Brynjolfsson and co-authors conclude that the real benefits from computerization could be of an order of magnitude (i.e. 10 times larger) than those that are normally recorded by growth accounting exercises with macro data.

[5] A further point is related to the differential impact of ICT on the organisational structure of large and small companies which may constitute a further point of analysis with special emphasis on two different but complementary phenomena: the externalisation and sub–contracting of non–core activities by large companies and the attempt of building networks by small and medium enterprises in order to cope with the technological change and the economic instability connected with the globalisation process..

interpretation for inter-firm and inter-sector variability in the impact of ICI on productivity (which the data show).

The types of organizational changes that are particularly relevant when thinking about ICT are related to organizational practices that influence the costs of information gathering and processing. As Malone (1987) and Radner (1993) noticed, hierarchical organizational structures (i.e. vertically integrated ones) typically emerge when communication costs are high: a hierarchical structure reduces the number of communication nodes between the different actors and hence reduces costs. However, since the ICT revolution has clearly reduced the costs of gathering and transferring information, we expect that the new technology permits and complements better with more horizontal structures. Analogously, the standardization of products if mostly appropriate in situations in which the production function is at the same time inflexible and subject to economies of scale. Flexibility and the extent of economies of scale are variables that are heavily touched by the ICT revolution [6] (think about telecommunications).

The role of organizational innovation in modern firms is stressed by the management literature (for a general discussion and references see Murphy, 2002), which documents how firms have responded to stronger competitive challenges trying to make a better use of knowledge, technology and human capital. This is reflected by the increasing role of intangibles, including human capital and the ability to continuously innovate.[7] As Murphy (2002) writes:

"*Strategic business thinking has shifted away from products, plants and inventory towards employees, technology and knowledge…Firms are adopting new knowledge management strategies which drive organizational change throughout the enterprise……*

Firm-level organizational change takes many forms, but can be classified into three broad streams (see Table 1):

i) the restructuring of production processes;

ii) management systems and employee involvement schemes;

[6] Notice that these changes can apply both to manufacturing and services (and hence perhaps explaining the increased productivity in services).

[7] For a macro perspective on the role of intangibles on productivity see Corrado et al (2009).

iii) *external re-organization emphasizing customer orientation, outsourcing, and firm networks and other collaborative arrangements.*

Table 1:

Production approaches	**Management Practices**	**External relations**
Total quality management	*Decentralization*	*Outsourcing*
Lean production	*Teamwork*	*Customer relations*
Just-in-time	*Knowledge management*	*Networking*
Business re-engineering	*Flexible work arrangements*	
	Flexible compensation	

Table 3 from Murphy (2002)

Internal re-organization typically affects the organization of production … and work practices while external re-organization is associated with the improvement of relations with customers and other firms. In practice, firms tend to apply an eclectic set of organizational practices, often spanning the three broad streams".

ICT are deeply related to many of these practices. The management practices more intertwined with ICT are:

- Lean production (including Just-in-time production) and re-engineering, in which ICT support the ability of the firm to have full, constant and detailed knowledge of the various aspects related to procurement and production. Examples of this are Computer Integrated Manufacturing (CIM) systems, functional to Just-in-Time production, and Enterprise Resource Planning (ERP), which requires tracking of all the activities, materials, workers and inventories and which is functional to the practice of business re-engineering. Internet-based procurement systems and other inter-organizational information systems have significantly simplified the relationship with suppliers (such as computer based supply-chain-integration). Such methods reduce direct cost of intermediation but also reduce the need for buffer investment and make deliveries more predictable, hence helping up-stream and down-stream firms to better predict their outputs and inputs. Some (Goldman Sachs, 1999) have estimated that these technological innovations are able to reduce procurement costs between 10 and 40%. These number might be too optimistic but even a reduction in the order of 5-10% would be extremely significant.

- Employee involvement in production since ICT works as a facilitator in the exchange of information among workers and between workers and management. Workers' involvement can be of different types: involvement at the suggestion stage (excludes participation to decision making), involvement at the job stage (how to actually perform a given routine) and also at the business/strategic stage (when workers fully participate in the design of the business model). Employee involvement can be coupled with teamwork in production or in strategic decision making.

- Relationships with customers. The management literature has shown that digitalization, mainly through the Internet, can have a large impact on the firm-customer relationship. Direct contact with consumers (during ordering or after-sale services such as technical support) is generally positively evaluated by consumers. Moreover, this direct contact with consumer coupled with internal organizational change has allowed firms to switch from build-to-stock to build-to-order models of production, generating consistent costs reductions through methods of just-in-time inventory management.[8] A clear application of this is the use of IT in Customer Relationship Management (CRM), such as the set-up of IT based call centres for customer care (including post-sale activity), technical centres and marketing.

- Outsourcing and delocalization. ICT allow firms to outsource (and delocalize) many activities, both for the supply of components and services and for CRM. This is more likely for non-core activities but is in no way restricted to them.

The management literature is full of case studies that show the potential and actual benefits arising from digitalization and workplace restructuring, but if one wants to obtain an estimate of their overall impact it is necessary to rely on large-sample empirical studies.[9] Among the first studies we have Brynjolfsson and Hitt (1996, 1996) and Lichtemberg (1995) where a production function is estimated including ICT capital and ICT labour among the regressors. Results from these studies show a clear positive relationship between productivity and ICT investment. These studies also show that the contribution of ICT capital to output (i.e. the output elasticity of ICT capital) is generally

8 For a discussion of the relationship between organizational change and firm performance –and the special role of ICT- see Murphy (2002).

9 As already mentioned, these studies need be conducted at the firm or plant level, since it is only at this lower level of aggregation that the phenomena of interest are measurable.

higher than the measured input share of ICT. A possible interpretation of this mismatch is the fact that the input share is under-measured, because the traditional measure do not take into account the role of (unmeasured) complementary investment (i.e. there are large but unmeasured inputs that are correlated with measured ICT). Evidence in favour of this hypothesis comes from studies that have looked at the long-run impact of ICT investment on productivity. For instance, Bryinjolfsson and Hitt (2000) find that the returns to ICT investment are higher when a longer period is considered (up to 7 years after the investment): the lag between the time the investment is made and the time in which it becomes mostly productive are interpreted as the expression of time needed (and the associated costs) for the re-organization that firms have to go through when they invest in ICT. The effects of ICT capital are up to five times higher in the long-run when compared to the short-run.

In Brynjolfsson, Hitt and Yang (2002), the authors document the fact that firms that invest in computers have an increase in their market evaluation of about 10 dollars for every dollar invested. However, such a high return is observed in firms that accompany the ICT investment with organizational change (specifically with a greater use of teams, broader distribution of decision rights and increased workers training). This is again interpreted in favour of the hypothesis that 1) ICT lower the costs of information acquisition and processing; 2) this leads to preference for organizational structures that are based on delegation and decentralized decision-making.

Bresnahan, Brynjolfsson and Hitt (2002) studied the impact of ICT and organizational change on the skill composition of the demand for labour. The authors find that IT investments and organizational change,[10] coupled with changes in products and services offered by the firm, induce a shift in the demand for labour that favours skilled labour over unskilled on. This result is taken as evidence that IT and organizational change become more productive when they are realized in an environment in which skilled labour is relatively more abundant. This is possible because the organizational redesign

[10] The proxy for organizational change is a linear combination of questions of team working (team use, team building activities, teamwork as a promotion criterion and the use of employee involvement groups or quality circles), and the extent to which workers have authority over their pace and methods of work. Notice that this variable is obtained from a cross-section (conducted in 1995 and 1996), while data on productivity and ICT are obtained from a 1987-1994 longitudinal dataset. Approximately 55% of the observations are from manufacturing, mining or construction and 45% are from services. Notice that the variable used by Bresnahan et al. (2002) can be interpreted as a proxy for organizational capital but hardly for organizational change, even if Bresnahan and coauthors argue the contrary.

that favours more decentralized decision-making and focuses on product and service development works better in environments in which skills are horizontally distributed. As for organizational change, the variables considered by Bresnahan, Brynjolfsson and Hitt (2002) are: increased delegation of authority to individuals and teams, greater level of skill and education in the workforce, greater emphasis on pre-employment screening for education and training.[11]

Particular attention to the issue of organizational capital and organizational change is present in the work by Black and Lynch and Ichniowski and Shaw. In Black and Lynch (2005) the two authors provide a taxonomy of organizational capital, which is divided into three broad components: workforce training, employee voice and work design. Workforce training is a joint decision undertaken by the worker and the firm to invest in additional skills training after an employment relationship has begun. Training is necessary when new technologies are introduced, but it is also very useful when new organizational structures -such a team work- are put in place. Employee voice is defined as "*organizational structures that give workers, especially non-managerial workers, input into the decision making associated with the design of the production process and greater autonomy and discretion in the structure of their work. Traditional forms of work organization are very task-specific; each production worker has a specific task to complete, and once they learn how to accomplish the task, there is little independent though involved. However, newer forms of organization involve giving employees, specifically lower level production workers, more input into the production process and greater opportunities to improve efficiency. As employees voice increases, firms are better able to tap into the knowledge of non-managerial workers*". Finally, work design includes the use of cross-functional production processes that result in more flexible allocation and re-allocation of labour in the firm[12] (changes in the occupational structure of the workplace, the number of workers per supervisor, the number of levels of management

[11] It is also interesting to note that the authors find that these practices are correlated among themselves, in other words they constitute a complementary work-system. Similar results have later been confirmed by studies that have looked at sectorial dynamics. Sectorial studies also confirmed that IT tends to be associated with smaller firms and less vertical integration, confirming the theoretical prediction that IT lowers procurement costs.

[12] Even if not an organizational practice per se, incentive-based compensation is often associated with an increase in organizational capital. As Black and Lynch say "*while incentive-based pay is not organizational capital per se, it is an important glue that holds the organizational capital together and keeps it within the firm*".

within the firm, the existence and diffusion of job rotation, and job share arrangements, the use of benchmarking).

After having defined and measured organizational capital, in Black and Lynch (2004) the two authors look at the impact of organizational change and ICT capital (proxied by the share of non-managerial workers that use a PC) on labour productivity. In their work the two authors use two cross-sections (1993 and 1996) from the Educational Quality of the Workforce National Employer Survey,[13] which contains a series of measures for organizational capital and technological change, and estimate productivity equation using both the 1996 cross-section and a longitudinal dataset, obtained from the two cross-sections matched with the Bureau of the Census' Longitudinal Research Database.[14] Their results confirm that high-performance workplace practices (incentive schemes offering profit-sharing or stock options) and employee voice (share of workers involved in the decision making process) are positively and significantly associated with higher productivity. The same holds for the share of non-managers who use computers at work (the proxy for ICT). Black and Lynch also show that establishments with unionized and traditional labour-management relationships (with little or no participation of employees in decision making) have lower productivity, compared to unionized plants that have adopted new workplace practices (they are also more productive than non-unionized plants that have adopted similar high performance workplace practices). These results lead the two authors to conclude that "*establishment practices that encourage workers to think and interact in order to improve the production process are strongly associated with increased firm productivity*". Moreover "*the higher the average educational level of production workers within a plant is, the more likely the plan has performed better than average over the period*".

Black and Lynch also estimate the overall impact of organizational capital on TFP growth in the manufacturing sector. They find that workplace practices contributed 1.4 percentage points per year, so that "*changes in organizational capital may have accounted for approximately 30 percent of output growth in manufacturing over the period*

[13] The Survey has been subministered to both manufacturing and non-manufacturing firms, but Black and Lynch only look at manufacturing firms.

[14] This is important because in previous work the two authors estimated the same equation with just one cross-section of the EQW-NES so that they were not able to focus on changes in organizational capital (besides facing the risk of bias in their estimate).

1993-1996, or 89 percent of multifactor productivity". This is indeed a very large number to be associated with investment in organizational capital, and the two authors are well aware that many of the components of workplace practices are strongly associated with technological change (such as IT investment). However, given that their specification does not include interaction terms between changes in organizational capital and ICT investment, they are not able to assess the role of the two factors when considered separately from the role they have when they are considered jointly.[15]

The work by Ichiniowski, Shaw and co-authors (well summarized in Ichiniowski and Shaw, 2003) is also very relevant. They use a methodology called Insider-Econometrics, which is a mix of extensive fieldwork (used to generate a detailed understanding of a specific production process, its technology and the nature of work involved) and rigorous statistical analysis, applied to specific sectors (in their case the steel industry), to study the impact of various work-place practices on firms' productivity. In a study of integrated steel finishing lines, Ichiniowski, Shaw and Prennushi (1997) identify four different systems of human resource management practices. At one extreme, there is what they call "high-involvement" human resource management system, which includes innovative practices across all the seven areas of human resource management considered (i.e. extensive employee screening, elaborate pay-for-performance plans, work teams, employment security guarantees, extensive labour-management communications, broad job definitions, ongoing training in skills and problem solving). At the other extreme, the "traditional" system is located with no innovative human resource management in any of the seven areas. Then there are the intermediate systems: the "communication" system that adds to the traditional system communication and information sharing and some team aspects, and, finally, "high-teamwork", which adds to "communication" the extensive participation in problem-solving teams and formal training programs. The results obtained by the two authors are quite astonishing: "*relative to the traditional*

[15] Interesting for the perspective of this study is also Lynch (2007), where the author looks at the determinants of organizational change. She finds that past profits tends to be positively associated with organizational innovations, indicating that only firms that have deeper pockets can afford the costs of investing in organizational capital. She also finds that firms with a more external focus and broader networks (those that export a higher fraction of their output, use benchmarking and are part of a multi-establishment firm) are more likely to learn about best practices and adopt them. Moreover, she finds that firms' investments in human capital, information technology, R&D and -more generally- in physical capital appear to be complementary and precede investments in organizational innovation. The issue of timing is important here because it shows how firms first invest in technology and then they shape their organization so as to make the investment fully productive. Finally she finds that organizational innovations are more likely in firms where the management is younger.

human resource management system, productivity is 6.7 percent higher under the innovative human resource management system, 3.2 percent under the "high-team work" system and 1.4 percent under the "communication" system". Ichiniowski et al. (1997) also show that in no case individual human resource innovative practices work when implemented alone: they only function as a bundle.

These results are very important because they show a positive monotonic relationship between innovative work practices and productivity. Moreover they are obtained for the same sector and the same type of output, so that they are really comparing apples-to-apples (something that is sometimes debatable in larger studies). The drawback is that these results are very difficult to generalize (but they are more generalizable than simple case studies).

In Gant Ichiniowski and Shaw (2000, 2002) the authors try to get a better understanding of the differences in the way employees perform their job tasks under innovative and traditional human resource management systems. In particular, they try to see whether workers employed in production lines using more innovative human resource management systems are actually working differently. The authors define the variable "connective capital" as a worker's access to the knowledge and skills of co-workers and assume that this variable is a key input for problem solving. The authors are able to provide a proxy for "connective capital" (interactions with workers with similar or different human capital) and find that indeed there exist stark differences in the patterns of work relationships based on differences in human resource management styles: "*in finishing lines with innovative human resource management systems, workers interact with a majority of other line workers, both within shifts and across shifts. In lines with more traditional human resource management practices, workers interact with a much smaller number of their peers or managers*". But if innovative HR systems do work, why then are they not adopted by all firms in the same product line? The answer is that the adoption of innovative HR systems is costly: new relationships among workers and between workers and management have to be created and this might be too complex for some firms or plants.

Evidence that shows the positive impact of innovative HR management systems on productivity exists also for the service sector, in particular showing the positive impact on service quality (i.e. relationship with customers).

One of the reasons behind the positive impact of workplace re-organization on productivity is that the former interacts with the information diffusion process. If speed, breadth and depth of information diffusion within the firm have an impact on firms' innovative capacity, then we have an additional source of ICT, organizational capital and human capital complementarity: firms can become more productive if they properly use ICT to obtain a more fluid information diffusion process, which works best when the firms' organizational structure and human capital is shaped so as to take advantage of ICT.[16]

Particularly interesting are the studies that have looked at the relationship between IT, organizational change, human capital and productivity growth for EU countries.

The first one is Caroli and Van Reenen (2001) who use French data to test the ICT-Organizational change-Human capital complementarity hypothesis, according to which recent managerial changes (possibly IT induced) shifting towards less hierarchical and more flexible organization forms, to be successfully implemented need workers with a high human capital level, since in such organizational forms workers have to deal with increased uncertainty and responsibility. New organizations are characterized by a shorter chain of command and a substantial portion of decision-making is delegated to

[16] The empirical literature on this is quite scant, but there is a paper by Aral, Brynjolfsson and Alstyne (2007) that it is worth mentioning. The three authors are able to study the social network of a medium size executive recruiting firm, using 10 months of e-mail data and accounting data detailing project co-work relationship. Over this period they divide the type of information shared in two groups. On the one hand they have messages that fall into the category of "event news" defined as simple declarative, factual information that is likely triggered by external events and is often of general interest to people in the organization. On the other hand they have "discussion topics", which are more specific, complex, procedural and characterized by back-and-forth discussion of interest to limited and specialized groups of people. They find that the diffusion of the two types of information follows different paths. In particular they find that "event news" –which are diffused pervasively through the organization- are influenced by demographic and network factors, but not by functional relationships or strength of ties with co-workers. On the contrary, diffusion of "discussion topics" (which is more shallow and characterized by more back-and-forth communications), is heavily influenced by functional relationships and the strength of ties, as well as demographic and network factors. It is also important to notice that access to information strongly predicts employees' productivity (the impact of the proxy for access to information has a stronger impact on productivity than traditional human capital variables, such as education and experience). These results, which obviously cannot be generalized beyond this case, are anyway interesting because they show that information diffusion –which is generally improved by the adoption of ICT- has a strong impact on productivity.

lower levels. As long as education helps in increasing the capability of solving problems, we expect these organizational changes to be correlated with higher education levels in the workforce. As a corollary, this also implies that organizational change implemented without the appropriate work-force ends up being unproductive.

Benefits from decentralization of decision making processes arise first because of the reduction in costs of information transfer and communication: information is processed at the level where it is used. Second, decentralization increases firms' reactivity to market changes. In a hierarchical environment, where tasks are more specialized and defined for each layer, we expect that reaction to market changes involve the coordination of a large number of activities. If the coordination costs are high, the reaction time might be slow. In more horizontal structures workers usually work in teams and, in each team, multiple skills and tasks are present, so that coordination costs are reduced and response to market change can be faster. Third, decentralization reduces monitoring costs. Finally decentralization might improve productivity through rising job satisfaction: workers are more involved, they participate at some level at the decision and implementation process and get more satisfaction from their job.

However decentralization does not come for free. Costs of decentralization can be summarized as follows. First, in the absence of centralized decision making there is a risk of replication of information processing. Second, reduced monitoring can lead to increased risk of errors. Decentralization also tends to jeopardize the exploitation of increasing returns to scale (in decentralized structures multitasking prevails, but multitasking reduces the possibility of obtaining returns from specialization, which is one of the elements of increasing returns to scale). Finally, workers might not like the additional risk and stress arising from being part of the decision making process and they might respond to this by reducing their effort and hence their productivity.

In general, higher skills are expected to improve the ability to process information: the benefits of decentralizing information processing are expected to be increasing in the skill composition of the workforce. Skilled workers are also more able to communicate, hence reducing the risk of duplication of information, and are also more apt to multitasking and easier to train. Caroli and Van Reenen argue that "*a higher skill level of the workforce tends to reduce the costs and increase the benefits of decentralization. In* *other words, skill appears to complement organizational change*". The major implications for empirical analysis are that: 1) organizational change leads to skill upgrading; 2) skill-intensive firms are likely to reap greater productivity growth from organizational change. The interplay between skill composition and organizational change is also affected by technology. More specifically, the introduction of ICT reduces the costs of ex-post monitoring, reduces the risk of mistakes and reduces the communication costs among workers, while at the same time increasing their ability to process information. All these aspects lead Caroli and Van Reenen to predict that high skills, organizational change and ICT diffusion are complementary.

Their results confirm the hypothesis that organizational change and the skill composition are complementary in a productivity equation. As for complementarity between organizational change (OC) and ICT, their results are mixed: on the one hand the interaction term is positive, indicating that positive interactions indeed exist. On the other one, the estimated coefficient is not significant at customary significance levels. The authors read their overall results of a clear indication of Skill-Biased-Organizational-Change, while –for the complementarity hypothesis between OC and ICT- they think that the evidence gathered is indicative of its existence and they justify the poor significance of the coefficients on the ground of likely multicollinerarity between OC and ICT. In other words, if ICT and OC are always strongly associated (because managers know that ICT investment is productive only when complemented with OC), then it is almost impossible to estimate the impact of each factor individually on the overall firm's performance.[17]

Crespi, Criscuolo and Haskel (2007) look at the issue of complementarity between ICT capital and OC using UK data from the Third Community Innovation Survey (which records info on firms' activity between 1998 and 2000, covering firms in manufacturing and services). The variable used to capture OC are the following: a) implementation of new or significantly changed corporate strategies (e.g. mission statement, market share); b) implementation of advanced management techniques within the firms (e.g. knowledge management, quality circles); c) implementation of new or significantly changed organizational structures (e.g. investors in people, diversification); d) significant changes in the firm marketing concepts/strategies (e.g. marketing methods). In

[17] The variable used by Caroli and Van Reenen for organizational change in France captures the presence of the following elements: de-layering (i.e. removing one or more managerial levels); use of just-in-time production, existence of quality circles, existence of total-quality-management.

particular, b) and c) are the aspects closer to the concept of OC discussed in the literature. The authors also consider the existence of process innovation as part of organizational change. As for IT investment, the CIS reports data on the amount of expenditures on acquisitions of machinery and equipment (including computer hardware) in connection with product or process innovation. This variable is then used to create a variable that captures the fraction of total investment that goes to IT. Their results indicate that there are significant returns to IT (30%) when OC is not controlled for. However, the returns to IT are reduced when a measure for OC is introduced among the regressors, indicating that OC and IT tend to be correlated. Finally, in the specification where they also introduce an interaction term between IT and OC (capturing the complementarity effect), they find that: 1) the intensity of IT investment per se has a positive but not significant impact on productivity; 2) OC per se has a negative but not significant effect on productivity; 3) the interaction term between OC and IT enters with a large positive and significant estimated coefficient, indicating the existence of strong complementarities among the two variables

These results are then interpreted as evidence in favour of the complementarity hypothesis for the UK. It is also interesting to note that the authors find that US-owned firms are more likely to introduce OC relative to other MNEs and exporters (but among these firms, OC is more likely than in UK non-exporting firms). This result is interesting when put in the context of the EU slowdown in productivity characterizing the late 20th century (especially if we think that UK firms were among the good performers). In other words, perhaps the EU economy is not growing as much as possible also because it is not fully benefiting from the gains that the ICT revolution, together with new management styles, would allow.

Giuri, Torrisi and Zinovyeva (2008), look at the issue of ICT-skill-OC complementarity in a panel of Italian manufacturing firms for the period 1995-2003. Their results indicate that there exist OC-skill complementarity but there is no evidence of significant and positive complementarity between ICT investment and OC or between skills and ICT investment.[18]

[18] The intent of this paper is close to ours. However there are some relevant differences. First, they use only two waves of the Indagine sulle Imprese Manifatturiere italiane, for the period 1995-2000 and subsequent observation are obtained from Bureau Van Djik's Amadeus dataset (they work with lagged

The complementarity issue has been recently explored by various studies. In the context of the ESSnet project on "Linking the micro-data on IT", funded by Eurostat and in which National Statistical Offices from 15 EU Countries have actively participated, it has become possible to look more precisely at the actual content of ICT utilization (as opposed to a generic monetary measure of investment in ICT) and, hence, at how the different types of ICT use tend to be complementary to organizational (and other types of) innovation. This project, for each country, collects and merges data from the Business Register, the Production Survey, the Community Innovation Survey (CIS) and the E-business Survey. It is hence possible to link together firm characteristics, firm economic and innovative performance and actual utilization of ICT (variables are on broadband penetration, use of mobile connections, use of ICT for ERP, use of ICT for CRM). Using such merged mesodata (i.e. data obtained aggregating firm level observations, according to specified characteristics such as sector, size, age etc.) for year 2008, Polder (2012) finds that the complementarity between the use of ICT for ERP and organizational innovation is quite high among all the 15 countries considered. However, when a more refined analysis that uses firm level data is conducted for the Netherlands alone, the results show no significant evidence of complementarity between ERP and organizational innovation.

It also worth noting that the research line on the complementarity between ICT and organizational capital in production has developed (until recently) in parallel to the investigation of the relationship between R&D, innovation and productivity. Starting with the seminal work by Griliches (where R&D is introduced as a regressor in a productivity equation to take into account the role of knowledge) such literature has matured and reached a structural interpretation with the fundamental work by Crépon, Duguet and Mairesse (1998) and the development of their CDM model, which tries to better understand the relationship between innovation input (R&D), innovation output (product and process innovation) and productivity, through a semi-structural model. However, recently (Polder et al. 2010) there has been an attempt to merge the two literatures, adding organizational innovation among the innovation output variables and ICT among

values for the explanatory variables, which are not available in the latter). Second, their dependent variable is value added and not labour productivity. Third, their specification is in levels and not in growth rates, and this makes quite a difference in terms of the obtained results and their interpretation (for a discussion see Crespi et al, 2007). In fact, our results only partially confirm theirs.

the innovation inputs (together with R&D), based on the recognition of the GPT feature of ICT. This approach does not directly look at complementarity (which is purely a measure of association), as it focuses on the impact of ICT on organizational innovation, which implies an hypothesis on the causation mechanism (ICT investment causes organizational innovation and not vice versa, due to the set-up of the CDM model). Using micro data from the Netherlands the authors find that, in manufacturing, ICT investment has only a minor and barely significant impact on organizational innovation, while in the service sector its effects on all types of innovation are larger and more significant. However, when ICT penetration is measured with the percentage of workers who have access to a broadband, then the positive effect of ICT on organizational innovation appears also in the manufacturing sector (but it is stronger for the service sector)..

A weak complementarity between organizational innovation and investment in ICT capital – proxied by the number of employees using a PC at work[19] - is found by Polder et al. (2012) in a study on Dutch data, in which variables such as the presence of an IT-based automation system for procurement and sales, access to high-speed internet, the percentage of workers having access to internet, broadband penetration (measured by the product of the two previous variables), the percentage of e-purchases and e-sales[20] are used to predict the probabilities of given innovation profiles, while the latter are then interacted with (the proxy for) investment in ICT capital in order to test the complementarity hypothesis in the productivity equation.[21]

These papers are especially interesting as they show that ICT capital and type of ICT use capture different factors. While the former captures the overall value of investment in ICT, it is only through the ICT usage variables (use of mobile connections, broadband penetration, use of ICT for ERP and/or CRM) that it is possible to have a better and deeper understanding of the strategic choices made by the firm in reference to the actual use of digital technology in the context of its organizational structure.

[19] This proxy for ICT investment is very debatable, as it does not take into account the additional investments in hardware and software.

[20] These variables are clearly plagued by problems of endogeneity.

[21] The main differences between Polder et al. (2010) and Polder et al. (2012) is that in Polder et al. (2010) ICT investment enters –together with the variables on ICT use- as innovation inputs into the innovation equation, while in Polder et al. (2012) the ICT usage variables enters into the innovation equation, while (proxied) ICT investment enters into the productivity equation, together with the predicted probability of the different innovation types.

3. Data description

The data used in this report are an unbalanced panel of Italian manufacturing firms, in the period 1995-2003, coming from the 7th, 8th and 9th "Survey[22] on Manufacturing Firms" by Unicredit-Capitalia, to which we added additional information coming from standard balance-sheet data. These surveys were conducted in 1998, 2001 and 2004 respectively, through questionnaires handed to a representative sample of manufacturing firms within the national borders. Questionnaires collect information over the previous three years. Each survey contains about 4.500 manufacturing firms[23] and in each wave the sample is selected with a stratified method for firms with up to 500 workers, whereas firms above this threshold are all included. Strata are based on geographical area, industry and firm size. As a result of this sampling method, each surveys contains on average about 32% of the firms included in the previous survey. While some variables are recorded in every year of each survey, so that, for instance, we have revenues for three subsequent years, for other variables, such as the existence of Organizational Change or ICT investment, we have a unique value for the whole survey. In particular, for ICT, the questionnaire ask firms whether in the previous three years the firm has invested in Information or Communication Technologies and, for those who answered "yes", it also asks for the monetary value for such investment. As for Organizational change, the questionnaire ask firms whether - in the previous three years - they have adopted organizational changes related to either process or product innovation. This means that for some variables (such as output or capital[24]), in year t wave we can get data for values in year $t-1$, $t-2$ and $t-3$. For other variables, such as OI or ICT, we only have a unique value for the whole wave.[25]

After a cleaning procedure and the construction of homogeneous time series over the surveys periods, we ended up with 583 firms observed over the 1995-2000 period (7th and 8th waves), 1206 observed in the 1998-2003 (8th and 9th) and 590 firms observed

---

22 We have also tried to sue the 10^{th} wave but the data presented many missing values and matching with previous years was unsatisfactory. Notice that the focus on the period 1995-2003 is probably the most interesting one since 1) this is the period in which the US experienced a productivity acceleration largely induced by investment in ICT and complementary assets and 2) it is a period in which investment in ICT was not saturated (if all firms invest in ICT we do not have enough variability in the data).

23 More precisely, the 7th wave contains 4,497 observations; the 8th wave 4,680 and the 9th 4,289.

24 The values for real output and real capital are constructed using balance-sheet data.

25 For this reason we have decided to work with wave averages for the variables for which we have multiple entries.

over the three survey periods. The selection of the sample allows us to keep 4,141 total observations (firm*survey). Table 2 shows the main descriptive statistics for the main variables of interests within the sample: average Production per worker (y) and its growth rate between two survey periods (Δlny), average Capital Stock per worker (k) and its across-waves growth rate (Δlnk), the average number of workers (L) and the number of workers engaged in R&D activities[26] (L_{RD}), Organizational Innovations (OI), Investment in ICT ($ICTI$), ICT investment as a fraction of total investment ($ICTR$), and the ratio between the number of workers with primary education or less and the number of workers with at least secondary education (EDU).

On average, around 39.2% of the firms introduced organizational innovations. The ratio of ICT investment to total investment equals 19.6% (but with a 21% standard deviation). The average investment in ICT amounts to €53.900 per firm. On average, the number of workers with low education is 3 times the number of highly educated workers, and a standard deviation equal to 4.32, indicates that few firms employ a high fraction of skilled workers. On average, firms are of medium size, as they employ about 86 workers and only 4 workers, on average, are employed in R&D activities. Also we report the size and geographical distributions of the sample firms. Most of them are located in the North and are Small-Medium in size. We also show two important features, the percentage of High-Tech firms is 31.8% while the percentage of firms which introduced at least one innovation (either product or process innovations) is 65% over the three survey periods.

Table 2: Descriptive statistics of the main variables.

	Mean	St.Dev.			Mean	St.Dev.
OI	.392	.488		*y*§	234.571	493.254
ICTR	.196	.205		*k*§	126.961	1182.31
EDU	3.07	4.32		*L*	85.6	192.7
ICTI§	53.909	199.02		$L_{R\&D}$	4.24	12.9
H-Tech	.318	.466		$\Delta \ln y$	.079	.383
INNO	.649	.477		$\Delta \ln k$	.284	.398
North	Centre	South		Small	Medium	Large
72.6%	17.4%	9.9%		63%	29.1%	7.9%

§ in thousand euros. See text for variables definition.
Sample size: 4141 firm-period observations.

[26] The values of these variables are first averaged within each survey period.

4. Econometric analysis

The growth rate of product per worker is derived from a simple Cobb-Douglas production function, where we assume that growth of the "productivity" parameter A depends linearly on a number of variables and their interactions.

$$Y_{it} = A_{it} K_{it}^{\alpha} L_{it}^{P\beta} \quad (1)$$

$$A_{it} = \exp\{A_{i0} + \delta' Z_{it}\} \quad (2)$$

where Y_{it} is real output, K_{it} is real capital, L_{it}^{P} measures the number of workers employed in production (i.e. excluding R&D workers). We assume that the firm's specific productivity Z_{it} depends upon K_{it}^{ICT} (the stock of ICT capital), O_{it} (the stock of organizational capital), EDU_{it} (a variable capturing the skill composition of the workforce) and the interactions among these.

Using (1) and (2), taking logs and differentiating we obtain the main specification of interest for firm i at (survey) time t:

$$\Delta \ln y_{it} = c + \alpha \Delta \ln k_{it} + \delta' \Delta Z_{it} + \gamma X_{it} + \varepsilon_{it} \quad (3)$$

where we allow for additional factors (X_{it}) that might affect the rate of productivity growth such as size, sector and area dummies. Notice that, when expressed in terms of productivity growth, the Z variables enter as changes, and we capture ΔZ_{it} with the following variables: a proxy for the intensity in ICT investment ($ICTR$: the average ratio of (real) ICT investment over total investments, computed over the previous three years[27]), a proxy for changes in organizational capital (OI: a dummy variable having a value of one if the firm has introduced an organizational innovation related to either product or process innovation in the previous three years), a proxy for the human capital composition of the workforce (EDU: a variable representing the average ratio of workers with primary education or less over workers with secondary education or more, computed over the previous three years) and their interactions.

Notice that growth rates are calculated as "long" rates between survey periods in which the firms are observed (see Data description above). This means that we first calculate

[27] We have also tried a number of different variables proxying firms' investments in ICT, for example a dummy variable taking value 1 if the firm has made some ICT investment in the previous three years, but we prefer the specification using the average ICT ratio, as the intensity in ICT investment is more precisely measured.

the average value of the variables within each period and then take 3-years log-differences.

We run OLS Estimation on different variants of this specification, taking into account the components separately and then jointly, i.e. their interactions. Firms fixed effects[28] are captured at least in part by size, area, sector dummies.

Results from the various specifications are reported in Table 3. The dependent variable $\Delta \ln y$ is the long-growth rate of per-capita real production, measuring labour productivity growth. The coefficient on the long-growth per-capita real capital stock is indicated by α.

In all regressions we control for firm characteristics like size, area and sector of production.

Table 3: OLS estimates of labour productivity growth

OLS	1	2	3	4	5
α	0.19615***	0.19614***	0.19593***	0.19580***	0.19655***
OI	-0.00283	0.04987**	0.01942	0.02049	-0.00317
ICTR	0.06099**	0.14660***	0.09937***	0.05949*	0.08633**
EDU	-0.00297**	0.00396	-0.00300**	0.00119	-0.00170
*OI*ICTR*		-0.13774**	-0.11739*		
*OI*EDU*		-0.00918***		-0.00788***	
*ICTR*EDU*		-0.01422**			-0.00851
Constant	-0.20448***	-0.23524***	-0.21307***	-0.21567***	-0.20904***
R^2	0.0782	0.0819	0.07899	0.08005	0.07848
N	4141	4141	4141	4141	4141

note: Note: Size, Area and Sector dummies are included in all regressions.
*** 1%, ** 5%, * 10% level of significance.

The first thing we notice (Table 3, col.1) is that, after controlling for size, area and sector dummies, we find evidence supporting the hypothesis that higher intensity in ICT investment (as captured by *ICTR*) increases firms' productivity (the coefficient is significant with 95% confidence). However, we have no evidence of a positive impact on productivity coming from organizational innovations: the coefficient on *OI* is not significant. Notice that *OI* is not significant even when it enters the productivity

[28] Notice that firm's fixed effects that might affect productivity levels are eliminated by differentiating the data, so that the issue here is about fixed effects that might affect productivity growth rates.

regression alone[29] (i.e. without the other two variables in ΔZ_{it}). The result for OI might depend upon the fact that, in this specification, we are not allowing for complementarities between OI and ICT intensity.[30] The sign on the coefficient for EDU is negative as expected: labour productivity is significantly increased when the share of workers with lower education decreases.[31]

When looking at the complete specification, in which we allow for all the relevant interactions (Table 3, col. 2), we find that both OI and ICT are (individually) positively and significantly correlated with productivity growth, while the coefficient on EDU becomes non significant (EDU might still affect productivity through complementarity with other assets). When looking at the interaction terms, we find that they are all statistically significant and negative. A negative coefficient on the interaction between the OI dummy variable and $ICTR$ implies that organizational innovations are substitutes and not complements to ICT investment. However, the negative coefficient on the interaction between OI and EDU implies that workers with higher levels of education are more productive when organizational innovations are introduced in the firm (the negative coefficient for the interaction of $OI*EDU$ means that OI and more educated workers are positively correlated with productivity growth). Similarly, the negative coefficient on the interaction between $ICTR$ and EDU implies that human capital (as captured by the inverse of EDU) is positively associated with the intensity of ICT investments in determining firms' productivity growth (the negative coefficient for the interaction of $ICTR*EDU$ means that more ICTR and more educated workers are positively correlated with productivity growth).

While it is sensible that - in the manufacturing sector - higher levels of human capital need to be associated with organizational innovations or with ICT technology to have an impact on productivity growth, the evidence we find on the ICT and organizational capital

[29] Results not reported here but the coefficient is equal to .0032 with a p-value equal to 0.78.

[30] The intuition is that, per se, OI might not be productive and becomes productive only when coupled by investment in ICT. Notice that the complementarity hypothesis does not imply symmetry: it is possible that ICT investment is not profitable unless it is coupled with OI, but this does not imply that OI investment is not productive unless coupled with ICT. We could have that OI is productive per se but becomes more productive when coupled with ICT and - at the same time - ICT is not productive unless coupled with OI (we could call this an asymmetric complementarity hypothesis). However, testing for this hypothesis might be quite tricky. In future versions of this work we will try to do that.

[31] When we try a different proxy for skill composition and use the within-wave average ratio of white over blue collar workers, we find that the estimated coefficient is generally not significant, even when we change the measure for ICT investments.

complementarity goes contrary to our expectations. We have tried to see whether these results could be due to potential correlation between the interaction variables and so we have regressed productivity growth on capital growth, *ICTR*, *OI* and *EDU* and one interaction at a time (we are also controlling for area, sector and size dummies). These results are reported in Table 3, col. 3, 4, and 5. We can notice that the last three columns of Table 3 confirm the results of the more complete specification of col.2: all the interaction terms are negative (even if not all of them are significant). This is evidence that the three types of "investments" are interrelated by a complementary/substitutability relationship and we cannot exclude them from the regressions.

The weak complementarity of ICT and organizational innovation in the manufacturing sector is not uncommon and has been found by the studies using Dutch data, especially when using variables related to ICT investment as opposed to ICT use. However, our results are even stronger: they actually show negative complementarity. The rejection of the ICT-organizational capital complementarity hypothesis for our sample could be due to the specificity of the Italian manufacturing sector in the period of observation. In the time interval 1995-2003, during which labour productivity was declining, it is quite plausible that manufacturing firms were investing less in ICT and more in changing the corporate structure, in the form of new work practices to improve work efficiency, or in the form of new business practices, to improve the quality of goods and services or the use of knowledge (see Biagi, Parisi, Vergano, 2008), or – finally – hiring temporary workers to reduce costs.[32] These changes might have been a priority with respect to investing into new technology and this would explain the negative coefficient on the interaction between ICT investment and organizational innovation.

[32] Organizational innovations encompass a broad definition of firms' changes in practices or structure. Work practices include providing continuous training, forming project teams, participation in the decision process, job rotation, incentive pay. Business practices include acquiring industrial property rights, unpatented know-how, management, design, operating instructions for production systems. See for example Sanida (2005).

5. Conclusions

This report analyses the complementarities between different activities which firms adopt in order to increase their performance or reduce their costs. Among these, we are interested in capturing potential interactions between organizational capital, human capital and ICT investment. In order to do this, we derived a specification for the average growth rate of labour productivity and estimated the impact of those different assets, plus their interactions, ceteris paribus. Introducing organizational innovations, investing into ICT capital or having a more educated workforce are individually positively correlated to productivity growth. Organizational innovations are complemented by a higher level of human capital. This complementarity might be explained if we identify organizational innovations with new work practices, which might require some skill capacity. On the other hand, ICT investments intensity is complementary to human capital intensity, and this is in line with our expectations, as IT workers are generally more skilled than the average worker. However, organizational innovations and ICT appear to be substitute activities on average. If we consider Italy in the period of observation, 1995-2003, during which labour productivity had sharply decreased, it is quite plausible that firms were investing less in ICT and other innovative activities (i.e. R&D) and more on corporate restructuring, in the form of new work practices (to improve work efficiency), new business practices (to improve the quality of goods and services or the use of knowledge), and switching from permanent to temporary jobs in an effort to reduce costs.

It could also be that the evidence contrary to the complementarity between organizational capital and ICT is due the characteristics of our dataset (reflecting the peculiarities of the Italian manufacturing sector). Our sample is largely made up by SMEs and there are theoretical reasons that justify the fact that the complementarity hypothesis might hold for large firms but not for SMEs. This is due to the fact that the cost of contemporaneous adoption of ICT investment and organizational change are too high for SMEs relative to their potential benefits (the amount of information that have to be processed is lower in SMEs and so is the number of management layers). In fact, many SMEs invest in basic ICT infrastructure (PC and Internet connectivity) that do not require skill upgrades or organizational changes to become productive. Moreover, SMEs might already be characterized by greater flexibility in working practices and lower monitoring and processing costs (so that the benefits from organizational change spurred by ICT are lower). Finally the labour force might not be sufficiently ample to permit modern organizational practices such as job rotation or team work. These factors might actually be at the root of the decrease in TFP observed for this sector.

Future research should go in the direction of disentangling the productivity effects of overall ICT investment from those of ICT use.

References

Aral S., Brynjolfsson E. And Van Alstyne M. (2007), "Productivity effects of information diffusion in networks", WP. 234, The MIT Center for Digital Business

Arrow K.J. (1962), 'The Economic Implications of Learning by Doing', Review of Economic Studies, 29:155-173

Bartelsman, E. J., Mark Doms (2000), 'Understanding productivity: lessons from longitudinal microdata', Journal of Economic Literature, 38: 569-594

Bessen J. (2002), 'Technology Adoption Costs and Productivity Growth: The Transition to Information Technology', Review of Economic Dynamics, 5, 443–469

Bessen J. (2003), 'IT Adoption and Productivity, A Reply to Diego Comin', Review of Economic Dynamics, 6, 252–262

Biagi F., Parisi M.L., and Vergano L. (2008): "Organizational Innovations and Labor Productivity in a Panel of Italian Manufacturing Firms", University of Brescia, Department of Economics Discussion Paper n.0813.

Black S. E. Lynch L. M. (1996), "Human Capital Investments and Productivity", American Economic Review, May, 86:2, pp. 263-267

Black S. E. Lynch L. M. (2001), "How to Compete: the Impact of Workplace Practices and Information Technology on Productivity", Review of Economics and Statistics, August, 83:3, pp. 434-445

Black S. E. Lynch L. M. (2004), 'What's Driving the New Economy: The Benefits of Workplace Innovation', The Economic Journal, vol. 114, Feb., pp. 97-116

Black S. E. Lynch L. M. (2005), "Measuring Organizational Capital in the New Economy", in C. Corrado, J. Haltiwanger and D. Sichel, eds. "Measuring Capital in the New Economy", University of Chicago Press, Chicago, 2005.

Bresnahan T., Brynjolfsson E., Hitt L.M. (2001), 'Information Technology, Workplace Organization and the Demand for Skilled Workers: a firm Level Analysis', Quarterly Journal of Economics, Feb. 2002: pp. 339-376

Bresnahan T.F. J.E. Trajtenberg (1995), 'General Purpose Technologies: Engines of Growth?' Journal of Econometrics 65 (Special Issue, January): 83-108

Broersma L., McGuckin R. H., Timmer M. P. (2003) "The impact of computers on productivity in the trade sector: explorations with Dutch microdata" De Economist n. 1

Brynjolfsson E., Hitt L.M., (1995), 'IT as a Factor of Production: the Role of Differences among Firms', Economics of Innovation and Technology, Vol. 3: 183-198

Brynjolfsson, E., Hitt. L.M., (1996), 'Paradox Lost? Firm-Level Evidence on the Returns to Information Systems Spending' Management Science 42(4): 541--58

Brynjolfsson E., Hitt L.M. (2000), "Beyond Computation: Information technology, Organizational Transformation and Business Performance", Journal of Economic Perspectives 14: 23-48

Brynjolfsson E., Hitt L.M. (2003), 'Computing Productivity: Firm-level Evidence', Review of Economics and Statistics, Vol. 85, N.4 (Nov.), pp. 793-808

Brynjolfsson E., Hitt L.M. and Yang S. (2002), 'Intangible Assets: Computers and Organizational Capital', Brookings Papers on Economic Activity, Vol. 2002, N.1, pp. 137-181

Brynjolfsson E., McAfee A., Sorell M. And Zhu F. (2007), "Scale without Mass: Business Process Replication and Industry Dynamics", mimeo.

Caroli E., van Reenen J. (2001), 'Organization, Skills and Technology: Evidence from a Panel of British and French Establishments', The Quarterly Journal of Economics, Nov. 2001, pp. 1449-1492

Cette G., Mairesse J., Kocoglu Y. (2002), 'Diffusion of ICT and Growth of the French Economy over the Long Term, 1980-2000', International Productivity Monitor, No.4, 27-38

Cohen W., Levinthal D. A. (1990), "Absorptive Capacity: A New Perspective on Learning and Innovation", Administrative Science Quarterly, Vol. 35, N.1., pp,128-152

Colecchia A. Schreyer P. (2002a), 'ICT Investment and Economic Growth in the 1990's: Is the United States a Unique Case?', Review of Economic Dynamics 5: 408-442

Colecchia, A., Schreyer P. (2002b), 'The contribution of information and communication technologies to economic growth in nine OECD countries', OECD Economic Studies 34

Comin D. (2002), ‘Comments on James Bessen’s ‘Technology adoption costs and productivity growth: The 70’s as a technological transition’. Review of Economic Dynamics, 5, 470–476

Corrado C, Hulten C. and Sichel D. (2009) ‘Intangible Capital and U.S. Economic Growth’, *Review of Income and Wealth* 55: 3 (September 2009), 661-685

Crépon B., Duguet E., and Mairesse J. (1998). ‘Research, innovation and productivity: an econometric analysis at the firm level’. Economics of Innovation and New Technology, 7: 115-158.

Crespi G., Criscuolo C. and Haskel J. (2007), Information Technology, organizational change and productivity growth: evidence from the UK, CEP Discussion paper n. 783, 2007

Davis, G., Collins R., Eierman M., Nance W. (1993) ‘Productivity from Information Technology Investment in Knowledge Work’, In: R. Barker, R. Kauffman, Mahmood (eds.), Strategic Information Technology Management, Harrisburg PA, 327-343

Doms M.E., Jarmin R. S., Klimek S. D. (2004) ‘Information technology investment and firm performance in US retail trade’ Economic Innovation and New Technologies, Vol 13(7), October, pp 595-613

Gant, J., Ichniowski C. and Shaw K. (2003), “Working Smarter by Working Together: Human Resource Practices and the Connective Capital of the Firm”, LSE, 2003.

Giuri, P., Torrisi S. and Zinovyeva N. (2008), “ICT, skills, and Organizational Change: evidence from Italian Manufacturing Firms”, Industrial and Corporate Change, Vol. 17, N. 1 pp 29-64

Goldman Sachs (1999), “B2B: To Be or Not 2B?”, High Technology Group Whitepaper, November

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

Gordon R.J. (2002), ‘Technology and Economic Performance in American Economy’, NBER Working Paper No. 8771

Greenwood J., M. Yorokoglu (1997), “1974”, Carnegie-Rochester Conference Series on Public Policy, 46: 363-382

Heshmati, A. (2003) ‘Productivity growth, efficiency and outsourcing in manufacturing and service industries’, Journal of Economic Surveys, 17:79-112

Hornstein A., Krussell P. (1996), ‘Can Technology Improvements Cause Productivity, Slowdowns?”’, NBER Macroeconomics Annual, 209-59

Hulten, C.R. (2000) ‘Total Factor Productivity: A Short Biography’, NBER Working Papers 7471, National Bureau of Economic Research, Inc

Ichniowski C, Shaw K. (2003), “Beyond Incentive Pay: Insiders’ Estimates of the Value of Complementary Human Resource Management Practices”, Journal of Economic Perspectives, Vol. 17, N. 1 Winter 2003, pp. 155-180

Ichniowski C, Shaw K. and Prennushi G. (1997), “The Effects of Human Resource Management Practices on Productivity”, American Economic Review, June, 87:3, pp. 291-313

Inklaar R., O’Mahony M. and Timmer M. (2005), “ICT and Europe’s Productivity Performance: Industry Level Growth Account Comparisons with the United States”, Review of Income and Wealth, vol. 51 (4), pp.505-536.

Jorgenson D. W. (2001), ‘Information Technology and the U.S. Economy’, The American Economic Review, Vol. 91(1)

Jorgenson D. W. (2003), “Information Technology and the G7 Economies”, World Economics, Vol. 4, No. 4, October-December, 2003, pp. 139-169

Jorgenson, D.W., Stiroh K. J., (1999) ‘Information Technology and Growth’, American Economic Review, 89: 109-115

Jorgenson D.W., Stiroh K.J. (2000a), ‘U.S. Economic Growth at the Industry Level’, American Economic Review, 90: 161-167

Jorgenson D. W., Stiroh K.J. (2000b) ‘Raising the Speed Limit: U.S. Economic Growth in the Information Age’, Brookings Papers on Economic Activity, No.1

Jorgenson D.W., Ho M.S., Stiroh K.J. (2002), ‘Projecting the Productivity Growth: Lessons from the US Growth Resurgence’, Federal Reserve Bank of Atlanta Economic Review, No. 3, 1-13

Lee B., Barua A. (1999) An integrated assessment of productivity and efficiency impacts of information technology investments: old data, new analysis and evidence, Journal of Productivity Analysis, August 1999, v. 12, iss. 1, pp. 21-43

Lee H., Khatri Y. (2003), 'Information Technology and Productivity Growth in Asia', IMF WP 03/15

Lehr, W., Lichtenberg F. (1999) 'Information technology and its impact on firm-level productivity: evidence from government and private data sources, 1977-1995', Canadian Journal of Economics; Vol 32

Lichtenberg F.R. (1995), "The Output Contributions of Computer Equipment and Personal: A Firm-level Analysis", Economics of Innovation and New Technology, 3, pp. 201-217

Loveman, G. (1990) 'An assessment of the productivity impact of information technologies,' Mimeo, Massachusetts Institute of Technology, September

Lynch, L.M. (2007), "The adoption and diffusion of Organizational Innovation: evidence from the U.S. economy", IZA DP N. 2819

Mehmet J. (1998) 'The Information Technology productivity paradox' Review of Economic Dynamics, vol. 1 pp. 551592

Mendelson H., Pillai R. R. (1998) 'Information Age organizations, dynamics and performance', Journal of Economic Behavior & Organization, vol. 38 pp 253-281

Milgrom P. and Roberts J. (1990), "The Economics of Modern Manufacturing: Technology, Strategy, and Organization", American economic Review, 80:3, pp.511-528.

Morrison, C.J., Berndt, E.R. (1990) 'Assessing the Productivity of Information Technology Equipment in the U.S. Manufacturing Industries', National Bureau of Economic Research Working Paper #3582, January

Murphy M. (2002), "Organisational Change and Firm Performance", OECD Science, Technology and Industry Working Papers, 2002/14, OECD Publishing, http://dx.doi.org/10.1787/615168153531

OECD (2002), 'Measuring the Information Economy', OECD, Paris, 2002

OECD (2003), 'ICT and Economic Growth', Evidence from OECD countries, industries and firms", OECD, Paris, 2003

OECD (2004), 'Understanding Economic Growth, Macro-level, Industry-level, Firm-level evidence', OECD, Paris, 2004

Oliner S. D., Sichel D. (2000) 'The Resurgence of Growth in the Late 1990s: Is Information Technology the Story?' Journal of Economic Perspectives, Vol. 14(4), pages 3-22

Oliner, S.D., Sichel D.E. (2002), 'Information technology and productivity: where are we now and where are we going?' Federal Reserve Bank of Atlanta Economic Review, No. 3, 15-44

Oliner, S., Sichel D. (1994) 'Computers and output growth revisited: how big is the puzzle?' Brookings Papers on Economic Activity: Macroeconomics 2

O'Mahony, M., van Ark B. (2003), "EU Productivity and Competitiveness: An Industry perspective. Can Europe Resume the Catching Up Process?", Luxembourg, Office for Official Publications of the European Communities.

Oulton N. (2001), 'ICT and Productivity Growth in the UK', Bank of England, Working Paper No. 140

Pakes, A. (2002) 'At what price? Conceptualizing and measuring cost-of-living and price indices' (Washington, D.C. national academy of sciences press)

Panko, R. R. (1991) 'Is Office Productivity Stagnant?' MIS Quarterly, June, 190-203

Pilat, D., Wölf, A. (2004), 'ICT Production and ICT Use: What Role in Aggregate Productivity Growth?', in OECD, The Economic Impact of ICT: Measurement, Evidence and Implications, OECD, Paris, pp. 85–104

Polder M., van Leeuwen G., Mohnen P., and Raymond W. (2010), 'Product, Process and Organizational Innovation: Drivers, Complementarity and Productivity Effects', UNU-Merit Working Paper 2010-0356, Maastricht

Polder M., Zand F., van Leeuwen G., and van Beers C. (2012), 'Complementarities between Information technologies and Innovation Modes in the Adoption and Outcome Stage: A Micro-Econometrics Analysis for the Netherlands', paper presented at the CAED conference 2012, Nuremberg.

Radner R. (1993), "The Organization of Decentralized Information Processing", Econometrica, 62, pp.1109-1146

Roach, S. S. (1989), 'America's White-collar Productivity Dilemma. Manufacturing Engineering', August pp. 104

Romer P. (1986), 'Increasing Returns and Long-Run Growth', Journal of Political Economy, 94: 1002-1036

Rosenberg N. (1982) 'Inside the black box: Technology and economics'. Cambridge University Press

Sanidas E. (2005): Organizational Innovations and Economics Growth, Edward Elgar ed.

Schreyer P. (2000), 'The Contribution of ICT to Output Growth', OECD

Schreyer P., Pilat D. (2001) 'Measuring Productivity', OECD Economic Studies, No. 33, 2001/2, (Paris) pp. 127-170

Solow R. (1956), 'A Contribution to the Theory of Economic Growth', Quarterly Journal of Economics 70: 65-94

Solow R. (1987), 'We'd Better Watch Out', New York Times Book Review, July 12: 36.

Stiroh, K. J. (2002), 'Information Technology and the U.S. Productivity Revival: What Do the Industry Data Say?' American Economic Review 92(5): 1559-1576

Timmer M., Ypma G., van Ark B. (2003), 'IT in the European Union: Driving Productivity Divergence?' Research Memorandum GD-67, Groningen Growth and Development Centre

Triplett J. E. (1999), 'The Solow Productivity Paradox: What Do Computers Do to Productivity?' The Canadian Journal of Economics, 32: 309-334

van Ark B., Inklaar R., McGuckin R. H. (2002) 'Changing Gear: Productivity, ICT and Services Industries: Europe and the United States' EPWP #02-02, The Conference Board

van Ark B., Inklaar R., McGuckin R. (2003) 'ICT and productivity in Europe and the United States. Where do the differences come from?' Paper for the SOM PhD Conference

van Ark J., Melka B.J., Mulder N., Timmer M., Ypma G. (2002), 'ICT investments and growth accounts for the European Union', 1980-2000, Research memorandum GD-56, Groeningen Growth and Development Centre

Varian H. R., Farrel J., Shapiro C. (2004) 'Information Communication Technologies' The Raffaele Mattioli Lecture Series, Cambridge University Press

Wolff, E.N. (1999) 'The productivity paradox: evidence from indirect indicators of service sector productivity growth', Canadian Journal of Economics, vol. 32, issue 2, pages 281-308

European Commission
EUR 25542 – Joint Research Centre – Institute for Prospective Technological Studies

Title: Are ICT, Human Capital and Organization Capital Complementary in Production? Evidence from Italian Panel Data

Authors: Federico Biagi, Maria Laura Parisi

Luxembourg: Publications Office of the European Union

2012 – 39 pp. – 21.0 x 29.7 cm

EUR – Scientific and Technical Research series –ISSN 1831-9424

ISBN 978-92-79-26921-9

doi:10.2791/99567

Abstract

Information and communication technologies (ICT) are believed to play a central role in determining productivity, especially when ICT investments are complemented in investments in Organizational Capital and Human Capital.
In this paper we explore the ICT-Organizational Innovation-Human Capital complementarities issue for the Manufacturing sector in Italy. We use data from the 7th, 8th and 9th waves of the "Indagine sulle Imprese Manifatturiere Italiane" by Unicredit (previously managed by Capitalia-Mediocredito Centrale), which contains information on ICT investments, organizational innovations, the skill composition of the work-force and on many other variables (measured at the firm level). From these three waves we create an unbalanced panel, made up by firms observed either in waves 7 and 8, in waves 8 and 9 or in waves 7, 8 and 9. After generating values for real product and real capital, we take the wave-to-wave variation in the log of productivity and regress it on a series of explanatory variables, including ICT investment, the presence of organizational innovations, the skill composition of the work force and their interactions. By taking first differences (wave-to wave differences) we are able to control for unobserved fixed effects which might be related to the endogenous variable (labor productivity) and to some explanatory variables.
On these differenced data we run OLS and find no evidence of the complementary hypothesis between ICT investment and organizational innovations, which is per se an interesting result, given that for many other (European) countries there exists significant evidence of complementarity. This is perhaps due to 1) the focus on manufacturing firms and 2) the fact that most firms in our dataset are medium-small firms (i.e. organizational change is more complementary with ICT investment for large firms). Our data also signal that the skill composition of the work-force is a strong determinant of productivity (either alone or when interacted with other potentially complementary assets). Finally, ICT investment is a complement to human capital in stimulating productivity growth.

LF-NA-25542-EN-N

As the Commission's in-house science service, the Joint Research Centre's mission is to provide EU policies with independent, evidence-based scientific and technical support throughout the whole policy cycle.

Working in close cooperation with policy Directorates-General, the JRC addresses key societal challenges while stimulating innovation through developing new standards, methods and tools, and sharing and transferring its know-how to the Member States and international community.

Key policy areas include: environment and climate change; energy and transport; agriculture and food security; health and consumer protection; information society and digital agenda; safety and security including nuclear; all supported through a cross-cutting and multi-disciplinary approach.

ISBN 978-92-79-26921-9

9 789279 269219

Publications Office