The skill content of technological change.[*]
Some conjectures on the role of education and job-training in reducing the timing of new technology adoption

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Abstract

This positional contribution has a twofold aim: the first is to explore the recent empirical literature developed around the issue of how the adoption of new technologies within the firm has changed the skill requirements of occupations; the second is to conjecture on the relationship, and on the relative sign, between technology adoption and firm sponsored on-the-job training. The basic idea is that the time-consuming dimension of the adoption process plays a direct role both in determining the profitability of the investment in new technology and in assessing the size of the productivity slowdown the firm eventually occurs after its introduction. On the extent that the timing of adoption depends on the workers' skill composition and on the distance between the skills *acquired for* the job and the skills *required by* the job, the deep understanding of the interplay between the mechanisms of human capital accumulation can be helpful in order for the firm to set suitable and efficient job-training strategies. During the last two decades the discussion around the impact of technological change on workers' human capital has been intense: the rapid diffusion of information and communication technologies (ICT) and computer-based machines (CNC, CAD), together with the large increase in the supply of highly-educated workers and rising returns to education, favoured the argument that technological change is characterized by a skill-biased nature (SBTC), leading to substantial changes in the division of labour and shifting labor demand towards employees with higher levels of education. On this purpose, different approaches have developed in the last decades that provide different evidence to a common research question. While a lot of national and international evidence still continues to support the SBTC hypothesis by employing 'traditional' aggregate measures of technological change and indirect measures of skill upgrading, a smaller literature is emerging that considers the heterogeneity of both technologies and skills at the workplace and aims at determining the demand of skills by the tasks occupations require. Even if new and interesting results emerge, many 'black holes' still remain, the most important of which seem to be the lack of theoretical and empirical models analyzing the role that school education and on-the-job training, and their interplay, can play in reducing the timing of new technology adoption.

Keywords: ICT, skill, timing of adoption, adjustment costs, education, training

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1. Introduction

The impact of technological change on the labour market, and human capital in particular, has always been a major concern of economic research. In the last decades, the relative increase in the supply of more educated workers in the industrialized countries has gone hand in hand with rising returns to education. This puzzling phenomenon has claimed in favour of the argument that technological progress intrinsically embodies a skill-biased nature. The skill-biased technological change (SBTC) hypothesis received extensive attention from both economists and policy makers[1]. In particular, since the seminal contribution of Nelson and Phelps (1966), economists have put substantial efforts in sustaining the idea that the introduction of a new technology within a firm, or within an industry, is complementary to the employment of a more educated workforce, who enjoys a comparative advantage in adapting to organizational changes (Welch, 1970; Bartel and Lichtenberg, 1987). However, this comparative advantage represents a sort of 'black box', a box that only recently some scholars have started to open. If, on the one side, changes in the nature of work have fostered the demand for the development of new skills, on the other side there is a twofold need to adequately define and measure skills and to understand how they effectively contribute to the economic performance of firms and aggregate economic systems.

This piece of work has a twofold aim: on the one hand it aims at exploring the empirical literature that, in the last years, has focused on the mechanism that induces new technology, in particular related to information and communication (ICT), to be complementary to higher levels of workers' education. On the other hand, it aims at suggesting a simple interpretative framework on the sign of the relationship between technological change and firm-level training. The basic idea is that the adoption of a new technology at the firm level is a time-consuming activity that depends on the human capital composition of the workforce; assessing how the introduction of new technology quantitatively and qualitatively changes the skill mix of workers is a major issue in order for the firm – and aggregate economic systems - to: (i) estimate the profitability of the investment in innovation activity, i.e. the acquisition of IT capital; (ii) assess the extent of the productivity slowdown that has been proved to occur after the adoption of new technology; (iii) calibrate efficient training programmes for reducing the adjustment costs.

[1] For a comprehensive overview of the literature see, among the others, Chennells and van Reenen (1999) and Acemoglu (2002).

At this early stage of the analysis, the most important question is: what do we know in facts about the relationship ‘technology adoption-skill mix of the firm’? The empirical literature developed on this issue is quite ample; less is known, instead, on the relationship between technology adoption and job training.

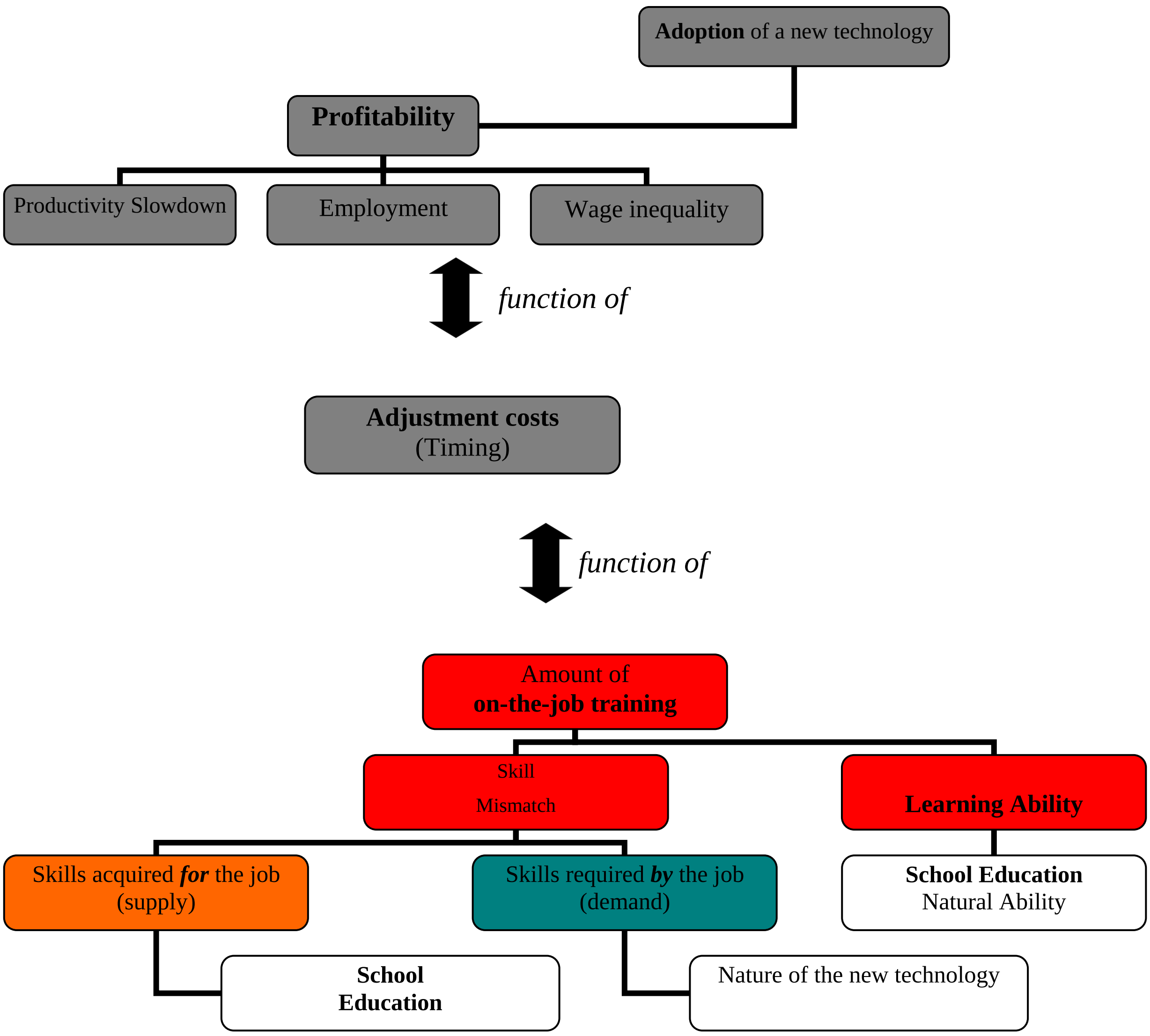
The empirical contributions investigating the technological change-skill mix relationship can be divided in two sub-classes: (i) ‘traditional’ empirical models employing indirect measures of skills and aggregate categories of workers, and (ii) ‘recent’ models that, by adopting a ‘task-’ or ‘job-oriented’ approach, put the attention to the multidimensional nature of skills. Within sub-class (i), a further distinction can be made between industry-level analyses and micro-level analyses where the unit of observation is mainly represented by the firm, the plant or the individual worker.

Papers belonging to the sub-class (ii) are mainly based on employee surveys or census data and aim at exploring the SBTC hypothesis in a deeper way. Particular attention, in fact, is given to the effect that different typologies of technology have on the skill mix the occupations require at the workplace.

Less, instead, is known on how the results on the effects of technology adoption can be utilized respectively: (a) by entrepreneurs in estimating the amount of job training to be provided in order to make workers full efficient with the new equipment; (b) how school education affects the effectiveness of training process; (c) how both skills acquired at school and skills acquired on the job affect the timing of adoption.

Aim of this short paper is to try to define an interpretative framework of analysis in order to answer questions (a)-(c), suggesting some remarks and leaving some questions open for future research. Figure 1 summarizes the research path suggested in the paper.

Figure 1. The human capital adjustment costs diagram



The diagram is characterized by different sets of boxes.

(1) The dark-grey-coloured area concerns the effects of technology adoption on the firm performance – i.e. the stream of expected quasi rents the firm can extract from the use of the new technology -, on the productivity slowdown the firm can occur during the initial phase of the introduction, and on workers wage and employment.

At the theoretical level these effects has been primarily investigated by utilizing formal models and tools typical of the endogenous growth literature[2]. On this purpose, two broad classes of models seem to emerge. On the one hand, models of R&D-based technological change and endogenous growth, founded on a 'production function-production cost view' of the firm, which study the role that the triptych 'technology, general human capital, and specific human capital' plays in shaping the average labour productivity function and offer a mix of suitable explanations for the US productivity slowdown and the increasing wage inequality occurring soon after the invention and diffusion of new major technologies. Among these models it is worth to mention Greenwood and Yorukoglu (1997), Caselli (1999), Helpman and Rangel (1999), Galor and Moav (2000), Gould *et al.* (2001), Violante (2002), Aghion *et al.* (2002), Krueger and Kumar (2002), Scicchitano (2005), Van Zon and Antonietti (2005), Weinberg (2005). The interaction between general/specific human capital and technological change at the firm level and their effects on aggregate growth is analyzed also by evolutionary micro-to-macro models based on the Becker-like distinction between general and specific human capital, on a Schumpeterian competition framework and on agents' adaptive learning patterns through genetic algorithms. On this field, the main contributions are Ballot and Taymaz (1996, 1997, 1999, 2001), Ballot *et al.* (2001). The main findings of these models, however, do not seem to be in line with explanations of SBTC, but appear to be more useful in shaping innovation and educational policies. In particular, there seem to be an optimal sequence for the firm to allocate its resources between innovation and training activities: (i) build a general human capital stock before the change in the technological paradigm; (ii) spend on R&D, and (iii) invest in specific human capital. In order to foster economic growth, the timing of training subsidies by public authorities is crucial as well: in fact, training should come before a major technological change, or early during that change. Finally, the subsidy should not focus on a particular type of training but, since they are complementarity factors for growth, should cover both general and specific training. In any case, both traditional and evolutionary endogenous growth models seem to rely on a mono-dimensional definition

[2] For a more detailed review of the main endogenous growth models on human capital and new technology adoption at the firm level see Antonietti (2005).

of human capital, so that even school education and firm-level training are just programmed at fostering respectively general and specific skills: but neither the former nor the latter typology of skills are considered in their multi-dimensional nature.

At the empirical level, instead, the major contributions on this field come from two classes of models that, starting from the recognition of the skill-biased nature of technological change, discuss the role of the firm adoption of new technologies, in particular computer technologies, on the skill mix of the workforce and on the skill requirements of jobs: models employing ‘traditional’ aggregate measures of human skills on the one hand, and models that, using employees surveys and microdata, adopt a ‘task’-oriented measure of skills on the other.

(2) The area characterized by red-coloured boxes concerns a field of research that do not seem to have been adequately explored both by theoretical and by empirical analyses. Moving from the idea that the major part of the adjustment costs consist in the *time* workers need to become fully familiar with the new technology, and assuming this time to be spent by employees in learning new tasks and operations at the workplace, a deep understanding of the factors affecting the quantity and the quality of on-the-job training becomes of paramount importance if the firm aims at reducing such costs. These factors are mentioned in the boxes below the red-coloured area, among which, in particular, the orange- and the blue-coloured ones represent variables on which recent empirical contributions have shed some light. Equation 1 summarizes the causal links.

$$(1) \qquad AtC = f\,[OJT] = f[(\vec{S}^R - \vec{S}^A)*(OJT\ hours);\ learning\ ability] \\ = f(school\ education,\ natural\ ability)$$

where *AtC* represents the adjustment (time) costs the firm has to bear for fully adopting a new technology, i.e. the difference between the time of introduction and the time of full operation ; *OJT* is on-the-job training; $\vec{S}^R$ = *f(nature of technology)* is the vector of the skills required by the job and $\vec{S}^A$ =*f(school education)* is the vector of skills acquired before the job by the individual.

Finally, the white boxes represent some determinants and issues that, at the moment, do not seem to have been fully understood.

The paper is arranged in 4 sections. The next section presents and discusses the main recent empirical results concerning the relationship between (information) technologies and job skill requirements. Section 3 presents some remarks and open questions: some conjectures will be made on the expected role that school education and learning ability of workers can play in affecting the efficiency of job-training and, thus, in lowering adjustment costs. Section 4 concludes and offers some further ideas for future research.

2. Technology adoption and the skill mix of firms: a look at the most recent empirical literature

It is commonly argued that the rapid spread of information and communication technologies (ICT) has led to important changes in the division of labour together with an outward shift in the demand for highly-skilled labour. Great part of these changes have reflected in the emergence of new forms of workplace organization, such as flatter management structures, larger autonomy for workers, the increasing adoption of human resource management practices, tele-working, and so on (Ichniowski *et al.*, 1997; Bresnahan, 1999; OECD, 2000; DeLiso, 2004). However, even if the relationship between ICT utilization and organizational change has been well documented, less information is available on the reasons why computerization motivate firms to change their internal structure, and, in particular, to change the skill requirements of their labour force. SBTC hypothesis tells us that the introduction of a new technology determines a subsequent higher demand for highly-educated workers, who are supposed to be more flexible and adaptable to changing environments than low-skilled workers. As a consequence, high-skilled workers receive a higher education-wage premium while low-skilled workers face a decline in their relative demand and, consequently, in their earnings. The overall conclusion is, thus, that SBTC is one of the major responsible of between- and within-groups wage inequality. These findings have been tested and somehow challenged by a growing body of empirical contributions. In particular, some authors have tried to open the 'black box' of SBTC by analyzing the reasons why ICT are complementary to employees with higher levels of education. What is commonly argued is that the adoption of ICT capital determines substantial changes in the demand for different types of skills at workplaces, which, in turn, translates in the educational composition of employees. On this purpose, the measurement of human skills becomes crucial in identifying two distinct sets of studies: on the one hand, a set of studies adopting 'traditional' aggregate measures of skills, based either on industry-level or on microeconomic data; on the other, a set of studies utilizing employee surveys and characterizing the 'multidimensional' nature of skills.

2.1. ‘Traditional’ industry-level analysis

Studies belonging to this kind of analysis usually utilize aggregate data-sets with the scope of finding a robust relationship between skills and technology use at a single industry level within a particular country. Among the authors, Autor *et al.* (1998), Berman *et al.* (1994), Berndt *et al.* (1992), Machin and van Reenen (1998), Haskel and Heden (1999), Siegel (1997) and Reilly (1995) offer interesting findings on US, British and German industries. Following Dunne and Troske (2005), it is possible to identify some common features.

(i) Two alternative but ‘traditional’ measures of *skill*s.

(i.i) The first derives from broad occupational categories available in plant-level data: i.e. non-production vs. production workers or white-collars vs. blue-collars. While the advantage of such a kind of measure lies in the high degree of detail that plant-level data ensure - typically 4-digit - the weak point stands in the high degree of simplicity, or roughness, with respect to measures extracted from worker-level data.

(i.ii) The second measure comes from the aggregation of worker-level data by education or by occupational grouping at the industry level, i.e. college graduates vs. university graduates or sales vs. managers and so on. In this case, while the level of data aggregation is higher, the measures of skill is more sophisticated, even if it does not appear sufficient in order to deal with the heterogeneity of human capital composition.

(ii) A measure of *technology* based on R&D expenditures, expenditures on computing equipment, or estimates of the computer capital stock within the industry. Hence, technology is a rather homogeneous factor that is mainly embedded in computing machines and usually comes from large firms’ research activity.

(iii) The main *findings* offer a general support for the SBTC hypothesis. A strong relationship between technological change and skill upgrading seems to emerge and this is reflected by increases in the fraction of non-production workers, generally more educated, with respect to production workers – or the fraction of white-collars on blue-collars – as far as new technologies are introduced into the plant or into the industry. In other words, computers replace manuals with non-manuals workers and, by stimulating labour demand for highly-educated individuals, are responsible of the increasing wage inequality occurring in the advanced economies.

Rounding up, studies focused on industry-level analyses appear to be more suited to answer the question if skills and technology are related at the workplace level. Little evidence, instead, is available on the role of workforce skill upgrading on the timing of technology adoption.

2.2. 'Traditional' micro-data analysis

Next to industry-level studies, others contributions make use of microeconomic data on workers, firms and establishments. While industry-level analyses offer a solid support to the SBTC hypothesis, a less clear-cut framework emerges from these studies. In particular, two contrasting versions seem to characterize the relationship between computer use and workers wages at the plant level. On the one side, authors like Krueger (1993) and Doms *et al.* (1997), analyzing individual data on US manufacturing plants, find a significant wage premium associated with computer use; on the other, authors like DiNardo and Pischke (1997), Card and DiNardo (2002) and Entorf and Kramarz (1997), report no evidence of a computer premium explained by shift in technology. DiNardo and Pischke (1997), in particular, find a wage premium associated with the use of pencils and sitting down on the job, and offer the explanations that, with the adoption of new information technologies, more productive workers are assigned tasks requiring the use of both computer and pencils. On the same direction seem to go. Entorf and Kramarz (1997) and Card and DiNardo (2002) who, either do not find any evidence on a computer premium, or do find that the wage differentials reflect differences in workers' unobserved ability, not captured by standard human capital variables like education, experience, tenure and age. In addition, other studies are characterized by a higher disaggregation of the workforce based on education and occupation groupings. Dunne and Schmitz (1995) and Doms *et al.* (1997), for instance, find a strong relationship between the adoption of advanced manufacturing technologies and the relative employment of more educated workers in spite of a decline in the employment of production labour.

Some interesting results come from papers which investigate the heterogeneous nature of technology. In a study on 79 US manufacturing firms, Siegel (1999) classify 12 different technologies into two broad categories: technologies used for streamline production techniques and technologies used in the quality improvement of goods. Using both econometric and case-study techniques, he argues that the magnitude of SBTC differs with the type of technology adopted by the firm: in particular, the skill upgrading occurs when the firm utilized technologies aimed at reducing production inefficiencies. In another, more recent, study Dunne and Troske (2005) use plant-level microdata on three types of technologies: network technologies, computing technologies, and computers. Skills are measured by the share of plant's payroll paid to non-production workers, that, as usual, are supposed to be more educated than production workers. Their cross-sectional findings are rather different from the previous evidence in that the relationship between the skill mix and technology adoption is now dependent on the type of technology considered: in particular, it is stronger when technology is associated to design and engineering functions.

Although these research studies differ in the results achieved, they adopt a common measure of skill, a measure that is strictly associated with the wage bill of different occupational or education categories of workers or that still reflects the relative share of skilled (non-manual, non-production) over non-skilled (manual, production) workers. Differences in wages reflect differences in education or differences in unobserved ability, but nothing is said on the distinction between the skills an individual acquire before being employed and skills that are required in order to perform a certain task. Moreover, technology is frequently mono-dimensional and measured as the share of IT capital on total capital stock.

2.3. Assessing the multidimensional nature of skill: the 'task-oriented' analysis

This section presents some recent studies that investigates the relationship between the dark-grey boxes and the blue-coloured box in the diagram of Figure 1. Only in the last few years, in fact, the focus of the analysis has shifted to an understanding of what new technologies do and how their introduction within the firm alters job skill demands. As previously stated, numerous economic studies have documented the strong relationship between the adoption of computer-based technologies and the increased demand for college- or university-educated workers. However, few studies asked what is the main cause of this association, that is few studies have tried to open the 'black box' of SBTC hypothesis.

Assuming implicitly that the workers' occupational duties approximate unbiased measure of their skills, a body of research, making use of the *Dictionary of Occupational Titles*, adopts a direct measure of skills in order to analyze how skill requirements of jobs have changed in the last decades. In particular, some interesting contributions point to investigate the relationship between changes in skill requirements of occupations and changes in the technology equipment used at the workplace. All of the these studies trust on two cornerstones: the first comes from the observations developed by economists, industrial sociologists and organization theorists on the 'core' skills that modern workplaces of industrialized economies require (Ducatel, 1994; Castells, 1998; Goldin and Katz, 1998). The skill categories developed in these studies are those identified by case studies or employee surveys as 'key' or generic skills required by modern, post-Fordist economies and by the increasing diffusion of ICT capital (Stasz, 2001). Differently from previous technologies, ICT capital stimulates the development of cognitive, non-manual tasks: computer-based-machines, in fact, are able to store, retrieve and act upon information. Not only, they can complement non-repetitive cognitive tasks, as analytical and interactive tasks, as well. The use of ICT capital enhances in particular problem-solving abilities, teamwork, computer-based management techniques (Green, 1998, Green *et al.* 2001, Stasz, 2001) next to collaborative work forms, the so called ‘high-performance practices’, like self-managed teams and quality circles (Osterman, 2000).

The second deals with the so called *limited substitution* mechanism between ICT and workplace tasks (Bresnahan, 1999) that is the main device by which SBTC increases the relative demand for non-repetitive skills for which employees with higher levels of education have a comparative advantage (Bartel and Lichtenberg, 1987). ICT capital, in fact, substitutes for repetitive, manual tasks – thus depressing the demand for low-educated labour – even if it does not take them completely over: this happens because ICT is mainly embedded in machineries like CAD and CNC machines that are able to perform these tasks but are not able to completely replace human dexterity.

Among the first contributions adopting a ‘task’ or ‘job’ analysis, Green *et al.* (2001), using British skill surveys and employing job analysis techniques, find that a higher wage premium is commanded by: (i) the possess of computing, professional communication and problem-solving skills; (ii) the participation in Quality Circles; (iii) the employment in jobs involving task variety.

Autor *et al.* (2003), instead, formalize a simple theory of how rapid adoption of computer technology modifies the occupation-specific tasks performed by workers at their jobs and ultimately the demand for human skills. Part of the novelty lies in the approach adopted: while previous studies relied on industry-level , plant-level or worker-level data, these new contributions build on an intuitive set of observations provided by organizational theorists, computer scientists and economists who focused on the study of what computers do and why computers and human capital are characterized by a complementary linkage[3]. The main conclusions that can be drawn are that:

(i) computers substitute for workers in carrying out a limited and well-defined set of cognitive and manual tasks, i.e. routine tasks. Task is supposed to be a “routine” when it is can be accomplished by machines following explicit programmed rules;

[3] Among the first class of economists we find Simon (1960) and Nelson and Winter (1982). Papers by Acemoglu (1998), Goldin and Katz (1998), Bresnahan (1999), Bartel *et al.* (2000), Lindbeck and Snower (2000) are focused on the technology-human capital complementarity.

(ii) computers complement workers in performing problem-solving, complex communication activities, i.e. non-routine tasks. Task is “non-routine” when the rules cannot be fully specified in computer code or programmes and cannot be fully executed by machines. In other words, non-routine tasks are characterized by a certain amount of ‘tacit knowledge’ that only humans can codify and accomplish.

If routine and non-routine tasks are considered as to be imperfect substitute in shaping labour productivity, then it is possible to measure changes in the task composition of jobs.

The measures of occupational skill requirements utilized are five: (i) non-repetitive cognitive/analytic; (ii) non-routine cognitive/interactive; (iii) routine cognitive; (iv) routine manual; (v) non-routine manual tasks. In addition, in order to further measure non-routine cognitive tasks, other two variables are selected: one related to interactive, communication and managerial skills, and one related to analytic reasoning skills. From a production function viewpoint, the main implications are that since the adoption of computer-machines has a high substitution impact with routine tasks – both cognitive and manual -, and is complementary to non-routine, non-repetitive tasks, an increase in the supply of informational inputs increases the marginal productivity of workers performing non-routine tasks. Table 1 shows some examples of workplace tasks (i.e. manual and interactive/analytical) according to the distinction “routine” vs. “non-routine” and shows some predictions on the impact at the workplace of computer adoption.

Table 1. Task model for the impact of computerization on four categories of job tasks

	Routine tasks	**Non-routine tasks**
Analytic and interactive tasks		
Examples	• Record keeping	• Forming/testing hypothesis
	• Calculation	• Medical diagnosis
	• Repetitive customer service	• Legal writing
		• Persuading/selling
		• Managing orders
Computer impact	Substantial substitution	Strong complementarity
Manual tasks		
Examples	• Picking or sorting	• Janitorial services
	• Repetitive assembly	• Truck driving
Computer impact	Substantial substitution	Limited opportunities for substitution or complementarity

Source: Autor et al. (2003), p. 1286.

Similar results appear in Wolff (2000), who adopts different measures of technological activity at the industry level and three main measures of job skills: interactive, substantive complexity, and manual. Outward shifts in computerization seem to positively related to changes in interactive skills as well as in substantive complexity, whereas no robust evidence is found for changes in manual skills.

An interesting piece of work is contained in Spitz (2003). Based on four cross-section employee surveys, she classifies job tasks into six categories: (i) analytical, such as mathematical logical reasoning and problem-solving; (ii) interactive, like interpersonal, organizational and managerial tasks; (iii) repetitive cognitive tasks such as bookkeeping, time-sheet accounting, inventory control tasks; (iv) repetitive manual, such as running and setting up a machine, sorting, collecting tasks; (v) non-repetitive manual, such as buildings construction, repairing, installing tasks; (vi) computing tasks, like programming and using application software.

Each task category is measured by the fraction of tasks a worker must perform within the particular category:

$$Task_j = \frac{\#Task_j}{\sum_{j=1}^{6} \#Task_j} * 100$$

In addition, a measure of skill supply is provided by the level of educational attainment of employees: employees without any formal vocational attainment are classified as low educated; employees with an apprenticeship or some degree of vocational college are classified as medium educated; finally, employees holding university or technical college degree are considered as highly educated. The empirical results support both the limited substitution relationship between IT capital and workplace skills and the argument that ICT increases the demand for higher educated labour by shifting the task composition of occupations towards analytical and interactive activities for which highly educated workers enjoy a comparative advantage. In conclusion, the impact of technological change on skill requirements depend on the educational structure within occupational groups.

3. Some open questions

In recent years many efforts have been made in the investigation of the mutual relationships between changes in the adoption of new technologies and changes in the skill composition of jobs. However, even if these efforts have been rewarded with new interesting findings, they leave some questions open though.

(i) The first question concerns the typology of data to employ. As we have seen, 'traditional' models are based on industry-, or plant-, or worker-level data. A deep analysis of the skill content of technological change, like the one developed in 'task' or 'job' models, is based on the use of case-study techniques (Stasz, 2001), job analysis (Green *et al.*, 2001) performed on cross-section employees surveys, or advanced econometric techniques applied to census data and codes merged with surveys providing information on the use of ICT and computer (as in Autor *et al.*, 2003 and in Spitz, 2003). At present, these data are mostly available for US, Great Britain, Germany and The Netherlands, and, to a less extent, for France, Sweden and Japan. Therefore, two 'black holes' need to be filled: the first concerns the possibility to collect and use panel data in order to better account for skill upgrading and technological change over time, while the second concerns the lack of data concerning other European, and other less developed, countries. Among European countries, Italy represents an interesting laboratory since, during the period 2000-03 at least, the percentage of university-graduated workers employed in manufacturing firms has remained very low, and even declined with respect to the preceding triennium. Next to this, Italy seems to face a decrease in the number of firms investing in new machineries and equipment, within the traditional sectors, in spite of an increase in the number of firms investing in R&D and in new equipment in the high-tech sectors (Capitalia, 2005).

(ii) The second open question concerns the source of occupation-specific skills. The models described above stress the relative advantage of being highly educated when adopting a new technology at work. Therefore, school education indirectly receive a lot of pressure from technological change. Moreover, these studies label as crucial the difference between the skills acquired *for* the job and the skills actually required *by* the job. What remains outstanding is the role that firm-level training should play in this context, and what is its relationship with school education. In other words, should the 'key' skills be learnt at school or/and on the job? Economists have always supported the idea that the education system should provide some basic set of skills that will enable an individual to acquire more specific skills on the job. However, if the adoption of IT capital rewards more key generic skills, and if these skills are not adequately acquired at school[4], then there is concern for firms to invest in general training, contrary

[4] Some research studies on US, German and Canadian manufacturing employees seem to confirm the fact that the most important place to receive the most useful skills for the labour market is the firm, or the workplace, and the most common source of labour skills is

to what human capital theory suggest. In contexts where the adoption of new technologies is fast, and given that the supply of skills from the education system is lower to adjust to the relative demand, the role of on-the-job training becomes crucial in filling the vocational competence mismatches of employees (Heijke *et al.*, 2003). To the extent they reduce training costs by providing higher learning abilities, together with the fact that new technologies require higher amounts of training, a justification for a higher demand for generic competencies and for higher education is found. From the firm standpoint, thus, it becomes crucial to know to what extent generic skills improve the ability of individuals to accumulate human capital on the job, in other words to know how much highly-educated individuals are able as learners. Unfortunately, little work has been done on a field that claims for a multidisciplinary approach between labour economics, cognitive sciences[5] and the theory of human learning. A useful support is given by some recent exploratory studies developed by scholars of the Research Centre for Education and the Labour Market (ROA) at the University of Maastricht (Smits, 2001; Heijke *et al.*, 2002, 2003; Meng and Heijke, 2005). With the aim of gaining insights into the different roles and the pay-off of three different groups of skills – i.e. field-specific skills that can be learnt in initial education, management skills to be acquired in a working context and academic skills that improve the learning process in initial education or in later training – they speculate on the role that school education should play in shaping the labour productivity of future workers. In particular university is argued to produce a mix of all types of human capital, within which field-specific skills play a central role. Not only: management skills result to be highly demanded in the labour market, so that on-the-job investments in their accumulation are paid off. General academic skills, finally, are obtained at the university and do not seem to pay off directly, but, rather, seem to play an indirect supportive role for the accumulation of field-specific and management competencies..

(iii) The previous open question gives the opening to the key remark of this paper: if, on the one side, we have evidence on the positive correlation between the use of (computer) technology and the strategic role of highly-educated employees at the firm level, little or no evidence is available on the time dimension of technology adoption, i.e. on the role that these skills play in shaping average labour productivity. That is to say: how do generic skills affect the time required by a worker to become fully familiar with the new technology?

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the continuous formal and informal job-training provided by firms (for more detailed information see Scicchitano, 2005 and van Zon and Antonietti, 2005).

[5] On this purpose, an interesting example is present in Antonelli and Maggioni (1997), who, following some seminal contributions in the theory of learning, formalize a function of human capital accumulation as a cubic specification of logistic type.

The timing of adoption at the firm level can be affected by different factors (Dunne *et al.* 1997). First, the existence of non-convexities in the cost for capital, i.e. the presence of fixed costs of adoption, so that technology adoption will result to be lumpy, with large changes observed. Second, erratic improvements in the leading-edge technology can induce the entrepreneurs to forego minor improvements or delay until improvements have sufficiently accumulated. Third, fluctuations in profitability for a given state of technology due to the nature and persistence of the demand and costs shocks. For instance, during the phase of adoption, plants may suffer output or productivity lost due to reorganization of the activity causing temporary disruption.

What seems clear, but still has not been adequately investigated, is that the timing of adoption is proportional to the vocational competencies mismatch of workers, that is the difference between the competencies acquired for the job and the competencies effectively required by the job. If this is true, then on-the-job training - and school education as an input affecting its effectiveness - may play a direct role in reducing fixed and opportunity adjustment costs and in reducing the duration and frequency of the fluctuations in profitability. Economic theory does not provide an unambiguous prediction of the sign of the relationship between technological change and the investments in training. One argument is that technological change makes formal education and previously acquired skills obsolete, thus increasing investments in specific-training and reducing the investments in school education. An alternative view, instead, is that education enables workers to adjust to and benefit from technological change (Nelson and Phelps, 1966; Welch, 1970; Bartel and Sicherman, 1998), so that there are higher incentives to invest in schooling than in specific, on-the-job, training. On this purpose, an interesting recent framework is provided by Borghans and ter Weel (2005) who test an assignment model of technology adoption, organizational change and division of labour using a panel of Dutch firms. In their set-up, the time a worker needs to perform a task is described by a function whose arguments are the task itself and a productivity parameter that decreases as a new technology, i.e. a computer, becomes more powerful over time. If the decrease in the time needed to perform a task is not proportional for all tasks or workers, then the adoption of a new technology can generate a (high-skill) bias in labour demand. What the model does not take into account is the role that on-the-job training can play in shaping the timing of adoption and in organizing the firm's internal division of labour.

Therefore, how much training the firm has to provide in order to minimize the costs of adjustment to new technology? The little evidence available tells us that although faster technological change requires more workers to be trained and perhaps more frequently (Lillard and Tan, 1986; Gill, 1988; Bresnahan *et al.* 2002, Galia and Legros, 2004), the duration of training – as measured as the average training time required to become fully qualified in the current job – needs not be longer (Mincer, 1989).

(iv) To the extent that the diffusion and adoption of ICT within the firm generate patterns of substitution of routine manual tasks, there should be for the firm a strong incentive to accelerate the delocalization of production modules employing less-skilled personnel. International fragmentation of production, thus, can lead to a stronger direct relationship between technology adoption and outward shifts in high-educated workforce, together with higher investments in labour training for the fact that R&D activities and high-skill-labour intensive production modules are developed within the firm's boundaries.

4. Conclusions

By exploring the most recent empirical literature, this short paper has tried to answer the following question: what do we know about the impact of new technologies on the skill mix of workers? The answer not only offers useful insights on the profitability of information technologies, but has important consequences for the role that school education and firm-level training should play in shaping the average labour productivity and in warranting profit margins for the firm by lowering adjustment costs – i.e. the time costs needed in order to generate efficiency units of labour.

The analysis of the most recent literature has stressed the growing need for microeconomic studies that take into consideration the heterogeneous and multidimensional nature of both technology and human capital. Research studies of more aggregate genre, based on industry-level data, seem to have clearly ascertained the skill-biased nature of technological change, in terms both of increasing demand for high-education workers and of increasing wage inequality between high- and low-skilled workers. However, when deeper explanations on the causes of SBTC are asked, the contributions become less numerous and seem to confirm that the adoption of new technology at the workplace (i) triggers off a substitution mechanism for routine manual tasks, thus reducing the demand for low-skilled individuals; (ii) enhance the development of non-routine manual and cognitive tasks for which more educated individuals have a comparative advantage.

Notwithstanding the importance of these analyses, the lesson we learn is that the adoption of new technology – IT capital in particular – plays a considerable role in assigning a strategic relevance at certain categories of skills. What we do not know is: (i) how firms can use these piece of information in order to calibrate effective training programs; (ii) if the adoption of new technology requires higher volumes of job training, and, thus, higher training (financial and opportunity) costs; (iii) to what extent on-the-job training can contribute in reducing the time required in order to fully perform a new task.

From the standpoint of economic theory, the answer to these questions can be helpful for improving the microeconomic bases of macroeconomic models particularly focused on the role played by human capital and endogenous technological change on aggregate productivity and economic growth[6].

Finally, the lack of data on European countries, and on less-developed regions, limits the analysis to the most advanced economies and does not allow any study on the transferability of the results obtained. Filling these gaps will be a challenge for future research.

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[6] Violante (2002), for instance, defines a *knowledge transferability function* when a worker move from unemployment, or from an old machine, to a new machine, as a function of the worker's skill bundle and the exogenous rate of technical change. Van Zon and Antonietti (2005), instead, define a labour productivity function as a geometric average of education and training time-units, implicitly assuming that the former provides the worker skills of a general type whereas the latter provides skills that are specific to the technology used for final output production.

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