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New Evidence on the Link between Technological Change and Employment: Extending the Neo-Classical Paradigm

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Number 0303

October 2003

NEW EVIDENCE ON THE LINK BETWEEN TECHNOLOGICAL CHANGE AND EMPLOYMENT: EXTENDING THE NEO-CLASSICAL PARADIGM

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Abstract

A burgeoning literature on "skill-biased" technological change (SBTC) reveals that investment in information and communications technology (ICT) is associated with workforce reductions and an increase in the demand for highly educated workers. Based on extensions of the neo-classical paradigm, researchers have also come to realize that the implementation of a new technology is often accompanied by organizational change. Two edited volumes by Marco Vivarelli, Mario Pianta, Pascal Petit, and Luc Soete provide important new evidence on the policy implications of these trends. We review these volumes and other recent studies and also provide new evidence on the relationship between technological change and organizational change, based on a comprehensive dataset of Italian manufacturing firms.

JEL classification: D20, J68, O33.
Keywords: complementarities; skill-biased technological change; compensation theory.

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1 - INTRODUCTION

A major issue on the European policy agenda is whether to increase labor market flexibility. There is considerable evidence indicating that labor markets have become more flexible in recent decades (Bentolila and Martin, 1994; Bertola and Ichino, 1995; and Oulton, 1995) and thus, more closely associated with the business cycle. Proponents of greater labor market flexibility assert that these policies would enhance economic performance, by reducing inflationary pressures and stimulating job creation. Another alleged benefit of such initiatives is that employers could more easily fire unproductive workers and re-deploy labor more efficiently. Supporters of these reforms also argue that they are necessary to level the playing field in international markets. Thus, such policies could arrest the decline in the global competitiveness of European firms, relative to their American counterparts, who do not face similar constraints.

It is important to note that these policy recommendations are typically based on theoretical and empirical results derived from neoclassical models, which fail to take account of institutional and organizational factors. Opponents of these reforms contend that institutional factors are quite different and of greater importance in Europe than in the U.S. Thus, neoclassical models may generate misleading policy conclusions in the European context. More specifically, they contend that abrogation of implicit contracts with workers will result in a decline in labor productivity and ultimately, lower economic growth, especially in the aftermath of hostile takeovers (see Shleifer and Summers, 1988; and Akerlof, 1983)

Complicating this issue are four major structural changes: (1) a rise in globalization, (2) acceleration in technological change, resulting from a dramatic increase in investment in information and communications technology (ICT) equipment and software, (3) the growing prominence of the service sector and a rapid increase in outsourcing and (4) a decline in the power of labor unions, especially in the U.S. and U.K. The rapid increase in international trade supposedly makes it more difficult for countries with inflexible labor markets to compete against foreign rivals, since labor cost and productivity (in real terms) differentials become more transparent.

A burgeoning empirical literature on "skill-biased" technological change (henceforth, SBTC-see Siegel, 1999) reveals that investment in ICT is associated with workforce reductions and other changes in the work environment that relate to flexibility. The service sector has also been growing at a more rapid rate than manufacturing. A concomitant trend in U.S. manufacturing industries has been a precipitous decline in the rate of private sector unionization (Potter, 2001). On the other side of the Atlantic, there has been a reduction in trade union power in some European countries, especially in the U.K. Oulton (1995) points out that in the 1960s and 1970s, it was difficult for firms to change work practices, due to trade union opposition. The U.K. government's labor-related legislation in the 1980s, designed to reform industrial relations, has made that process much easier for firms. A related point is the nature of the relationship between unions and the implementation of new technologies. Evidence from the coal industry (Link and Siegel, 2002) suggests that unions sometimes oppose new labor-saving technologies, even when there are major safety benefits associated with the implementation of the new technology.

Two recent books edited by Marco Vivarelli and Mario Pianta (2000) and Pascal Petit and Luc Soete (2001) shed important new light on these trends and their relationship to employment and labor flexibility. These volumes also present some evidence on the relationship between technological change, organizational change, and economic performance. The goals of this essay are to synthesize some of the results presented in these volumes and integrate them with broader theoretical and empirical evidence on these topics. We also present some empirical evidence on these phenomena from Italian manufacturing firms. Our research reveals that the critical question regarding the efficacy of policies to promote labor flexibility concerns how these initiatives affect the propensity of firms to innovate. We conjecture that the effects of enhanced labor market flexibility on innovation will depend on a series of institutional factors, which are typically ignored in neo-classical studies.

The remainder of this paper is organized as follows. The next section discusses recent studies of SBTC resulting from investment in ICT on labor demand. Section 3 reviews some of the evidence presented in the two edited volumes, while Section 4 integrates this evidence with a discussion of the theoretical approaches hinging on the complementarity between technological change and organizational change. Some recent empirical studies that build on these theoretical arguments are reviewed in Section 5. The final section present a synthesis of these findings and also highlights some policy conclusions.

2 - EVIDENCE ON "SKILL-BIASED TECHNOLOGICAL CHANGE"

Most empirical studies of SBTC are based on estimation of wage equations or cost functions, with the inclusion of dummy variables often serving as proxies for technological change. The cost function approach is desirable because it allows the researcher to formally test for the non-neutrality of technological change by examining the sign (and significance) of the coefficient on the technology variable. More importantly, this framework allows us to examine what may be a more relevant dependent variable: changes in share of highly skilled or educated workers, relative to those with less skill or education.

A commonly-used approach, employed in Berman, Bound, and Griliches (1994), is to estimate the following restricted labor cost function:

(1) $LC_i = f\,(W_i, TECH, Y, t)$

where LC is labor cost, W_i is the wage of the ith type of worker, $TECH$ is a proxy for technological change, Y is output, t is time, and f is assumed to have a translog form. Invoking cost minimization and Shephard's lemma ($S_N = \partial lnLC/\partial lnP_N$, where S_N is the share of non-production labor in total employment or labor cost), constant returns to scale, homogeneity of degree one in prices, and taking first differences yields:

(2) $ds_N = \beta_0 + \beta_1\, d\, ln\, (W_N/W_j) + \beta_2\, d\, ln(R/Y) + \beta_3\, d\, ln(C/I) + u$

where the authors include two proxies for technological change: *R&D* "intensity," or the ratio of R&D expenditures to sales (*R/Y*) and the ratio of expenditures on computers to total capital investment (*C/I*), and u is a classical disturbance term. If $\beta_2 > 0$ or $\beta_3 > 0$, we have evidence of "skill-biased technological change," or the notion that technological change benefits workers with higher levels of education or skill. Paul and Siegel (2001) extend this framework by estimating a dynamic flexible cost function model, which allows for quasi-fixed inputs, a more general functional form for the cost function (the Generalized Leontief functional form), and also includes measures of trade and outsourcing as independent variables.

A summary of some recent studies of SBTC involving ICT investment is presented in Table 1. Note that despite the use of different methodologies and analysis of data from different countries at different levels of aggregation (individual, plant, firm, and industry levels), each set of authors reports evidence that is consistent with the existence of skill-biased technological change in the U.S. and U.K. That is, these researchers generally find that some proxy for technological change (R&D, computers, adoption of advanced manufacturing technologies) is positively correlated with wages and shifts in labor composition in favor of highly skilled or highly educated workers.

One of the most important developments in empirical analysis of skill-biased technological change has been the creation of databases that match workers to their place of employment. Traditional studies of the labor supply behavior of individuals have suffered from limited information regarding the demand for a worker's labor. To understand the nature of this demand, and to help sort out the determinants of intra and inter-industry wage differentials, it is helpful to simultaneously explore data on the characteristics of workers and firms. Note that conventional datasets used in labor market studies, such as the CPS, the National Longitudinal Survey (NLS), or the Panel Study of Income Dynamics (PSID), do not have detailed information on the employer.

Researchers at the U.S. Census Bureau (see Troske, 1998) have constructed the Worker-Establishment Characteristic Database (WECD), a file that links detailed demographic data from the 1990 Decennial Census to comprehensive information on plants contained in the Longitudinal Research Database (LRD). The LRD is a compilation of Data on establishments from the U.S. Census of Manufacturers (CM) and the Annual Survey of Manufacturers (ASM). This file has also been linked to the Survey of Manufacturing Technology (SMT), which provides detailed information on advanced manufacturing technology usage.

The linked version of the WECD and SMT has been analyzed by Dunne, Haltiwanger, and Foster (2000). The authors report a positive correlation between the share of non-production workers in manufacturing industries and investment in computers. They find that the strength of this association is growing over time. Finally, it appears that SBTC is associated with greater dispersion (variation) in wages and labor productivity (across plants, within industries) over time.

Three wage-based studies from the U.S. and U.K. provide additional support for SBTC. Bartel and Sicherman (1999) analyze worker-level data from the NLS matched to industry-level data. They find that there is a positive correlation between wages and proxies for technological change and that this relationship is stronger for non-production workers than for production workers. Finally, their findings imply that the SBTC wage premium can be directly related to enhanced demand for ability in industries experiencing technological change. Haskel (1999) and Haskel and Heden (1999) analyze plant and industry-level data from the U.K. They report a strong positive correlation between relative wages and investment in computers. The authors estimate that the wage premium for skill grew by 13% in the 1980s in the U.K and that computers account for about half of this increase. They also report that computerization reduced the demand for manual workers (both skilled and unskilled workers).

Siegel (1999) collected comprehensive, firm-level panel data on the actual usage of advanced manufacturing technologies and concomitant, detailed changes in labor composition for 79 Long Island manufacturing firms. Note that these data are extremely rich because they constitute *direct* measures of technological change (as opposed to proxies for technological change), different *types* of technological change, and much finer measures of labor input than the typical production/non-production worker split. Estimating a variant of the model outlined in equation (2), he found that the implementation of a new technology leads to downsizing and a shift in labor composition and compensation in favor of white-collar workers. More importantly, the empirical findings reveal that there is considerable heterogeneity in downsizing and skill-upgrading across different classes of technologies. Thus, the magnitude of the skill-bias may depend on the *type* of technology that is implemented.

As noted earlier, Paul and Siegel (2001) estimate a dynamic, flexible cost function (i.e., a generalized Leontief functional form) at the 4-digit SIC level for U.S. manufacturing industries. This approach obviates the need to impose restrictive assumptions regarding producer behavior. More importantly, it allows the authors to simultaneously examine the impacts of trade, R&D, computers, and outsourcing on labor composition. The authors report that technology has a stronger impact on shifts in labor composition in favor of highly educated workers than trade or outsourcing. The effects of computers and R&D do not appear to differ substantially. Trade also has a negative impact on the demand for less educated workers, but it is not associated with an increase in demand for more educated workers. Outsourcing appears to have a relatively small negative impact on demand across all education levels, with the strongest effects for workers with less than a college degree. Perhaps their most interesting result concerns the interaction between trade and computers. Specifically, they find that trade induces computerization, which exacerbates the negative impact that each factor has on the demand for workers without a college degree, and augments the positive effects that each factor has on the demand for workers with a college degree. Thus, models that ignore these indirect effects may underestimate the overall impact of trade on labor composition.

Finally, Piva and Vivarelli (2001 and 2002) explore two additional factors that might induce SBTC: globalization and organizational change. They hypothesize that an increase in the volume of world trade and Foreign Direct Investment (FDI) could have important effects on the employment structure in developed and developing countries. Globalization might also stimulate organizational change. The authors test these hypotheses using a panel dataset of Italian manufacturing firms. They find strong evidence of an upskilling trend, which appears to be mainly a function of the internal organizational restructuring implemented by companies. However, technological change and FDI seem to have a negligible effect on SBTC. The authors caution that it may be inappropriate to generalize their findings, since few Italian firms choose to internationalize via and their technological strategies tend to favor the acquisition of technological know-how through embodied technical progress at the expense of formal R&D activity. However, their results underscore the importance of considering organizational change in studies on SBTC, a point that we will elaborate on in Sections 4 and 5.

An intrinsic limit of the SBTC approach is that it is focused only on the *relative* impact of innovation across employment groups (e.g., blue and white collar workers), while its *absolute* effect is disregarded a priori. That is, understanding whether technological change modifies the relative demand for skilled and unskilled workers represents only one side of the problem: taking into account that labor-saving technological change may imply an absolute reduction of both the skilled and unskilled workforce constitutes the other. Both of the edited volumes reviewed in the following section explicitly investigate the overall employment impact of innovation.

3 - NEW EVIDENCE ON TECHNOLOGY AND LABOR DEMAND

The book edited by Marco Vivarelli and Mario Pianta (2000) departs from the conventional economic view that unemployment arises due to labor market imperfections or business cycle effects. Instead, the editors allege that long-term technological factors can be of paramount importance in determining differences in employment patterns across countries. More precisely, they maintain that an adequate understanding of the unemployment problem must be based on a consideration of various structural factors, such as industrial policies, changes in the relative importance of industries within countries, and technological change.

This idea is clearly exposited in several empirical chapters and further developed in three theoretical papers. In the first paper, Lundgren examines learning and training in a broad social context. Next, Reinert analyzes targeted policies for innovative sectors and those with a strong potential for job creation, noting that many advanced nations have implemented such policies in the course of their industrial development. Finally, Karamerloglu and Ansal study the efficacy of compensation mechanisms in developing countries.

On the empirical side, Spiezia and Vivarelli analyze growth and employment statistics from OECD countries. The authors conclude that while North American countries were able to couple economic and employment growth in recent decades, European countries were characterized by "jobless growth." They assert that this difference can be explained by two factors: (a) variation in patterns of technological change, i.e., differences between the rate of product and process innovations in the U.S. (and Canada) and other OECD nations and (b) differences in the relative effectiveness of compensation mechanisms, that is, those economic forces that counteract the effects of reductions in employment due to technological progress. Economic theory suggests that such compensation occurs via “new machines,” “decreases in prices,” “new investments,” “decrease in wages,” “increase in income,” or “new products.” (for a detailed theoretical analysis of the “compensation theory”, see Vivarelli, 1995).

In another empirical chapter, Simonetti, Taylor, and Vivarelli shed further light on the key factors that moderate the effects of technological change on employment. They outline a system of seven simultaneous equations, which they use to assess the relative magnitude of each compensation mechanism. The authors estimate these equations with data from four OECD countries and find that variation in certain dimensions of performance can be attributed to differences in national institutional structures. For instance, process innovation has a strong positive impact on productivity and a negative effect on employment in Italy and Japan. On the other hand, product innovation results in an increase in total consumption only in the U.S. More generally, their results indicate that compensation mechanisms “via new incomes” work well in each country, although positive effects on consumption are partially offset by increases in productivity that led to reductions in employment. Moreover, the mechanism “via decrease in wages” is effective only in the U.S., which has the most flexible labour market.

In a similar vein, Piacentini and Pini present evidence in another chapter suggesting that the relationship between growth and employment in OECD nations is mediated by critical industry and country specific effects. For instance, they find that *jobless growth* is a dominant feature in the primary and secondary sectors. The authors also report that the employment elasticity of growth is highly negative for European nations, even during periods of significant growth. On the other hand, there are positive elasticities between employment and growth in the service sectors for all countries. The authors examine linkages between growth and employment based on a theoretical model where increases in productivity arise due to increasing returns to scale and productivity increases stimulate growth in overall demand. They find that the latter effect stimulates employment because productivity growth results in an increase in exports, although this employment effect is partly offset by substitution that arises from embodied technological progress (incorporated in capital goods).

Piacentini and Pini also analyze the effects of innovation on employment. They find that R&D expenditure, which is considered to be an input of innovative activity, stimulates the accumulation of capital goods and thus, has a negative impact on industrial employment. On the other hand, the authors report that indicators of innovative output have a positive effect on export performance. They also examine employment dynamics in seven OECD countries during the early to mid-1990s. Among the European countries considered, Sweden, the U.K., Italy, and Germany show the poorest performance with respect to job creation, while France and West Germany present nearly steady employment patterns. We believe that these findings would not hold if the data were extended to the end of the decade, for the U.K. However, this does not detract from the overall conclusion of the Piacentini and Pini chapter, which is that demand growth is a necessary, but not a sufficient, condition for fostering job creation.

The conventional view of technological change treats innovation as a undifferentiated process. This disregards the traditional distinction between process and product innovation, as well as technology strategies pursued by firms, the structure of the economy, and the particular histories of national economies. In his chapter, Pianta asserts that R&D expenditures are, at best, an imperfect measure of innovative effort. Thus, he suggests that a better understanding of the technological impact on employment can be obtained by considering the costs of such "non-R&D" activities as design, engineering, pre-production development costs, and costs associated with the acquisition of innovative capital goods from external sources. The latter may be particularly relevant for small and medium enterprises, which normally lack formal R&D units (Metcalfe, 1995). Furthermore, the author hypothesizes that heterogeneity in industries should be also taken into account, given that the rate of product innovation and job creation varies substantially across industries.

Pianta examines the validity of the latter assertion, based on an econometric analysis of industry level data from five countries that participated in the EU-sponsored Community Innovation Survey (Evangelista *et al*., 1997). The results suggest that, across manufacturing industries, demand growth (the change in value added over the 1989-1993 period) and prevalence of product innovations (share of R&D expenditures devoted to product innovation) are crucial positive factors for employment, while labour cost per employee and export orientation do not significantly affect the employment performance. These findings lead the author to conclude that "a fundamental reason for the worse employment performance of Europe relative to US and Japan has been the European weakness in the manufacturing (and service) sectors dominated by product innovations".

Much of the empirical literature on technology and innovation has focused on the manufacturing sector, since data on investment in technology are readily available in these industries. Unfortunately, there has been little systematic analysis of the antecedents and consequences of innovative activity in the service sector. The chapter by Evangelista fills this gap, based on a comprehensive innovation survey of Italian firms. He provides an overview of the innovation process in the service sector, including R&D, design, software, training, investment in machinery, and marketing. Consistent with some of the evidence commonly found from the manufacturing sector, he finds a positive relationship between proxies for innovative activity and firm size. There is also substantial heterogeneity in patterns of innovation across service industries, with the banking, insurance and other financial services industries reporting the highest rate of innovative activity. He also finds that the acquisition of new machinery and equipment constitutes one of the main sources of innovation, although in telecommunications and computer software formal R&D plays an important role. Industries that devote a substantial share of their innovation expenditure to software are advertising, banking, insurance and other financial services.

Evangelista also analyzes the relationship between innovation and employment, reporting that the impact of innovation on employment varies inversely with firm size. Indeed, firms with less than 200 employees increased their total employment as a consequence of the introduction of innovation, while innovation led to a significant reduction in total employment in very large firms. Moreover, innovation tends to displace workers with low levels of skill and induces an increase in the demand for high-skilled labor, especially in large firms (defined as companies with more than 200 employees). Finally, Evangelista's database allows for the identification of three clusters of sectors, grouped according to the overall impact of technology on employment and the presence of skill-biased effects. In engineering and computing, post and telecommunication and technological consultancy, innovation exerts a strong positive impact on employment and strong skill-bias effects. Both these effects are moderate in the waste, land and sea transportation, travel services, retail, hotels and air transport sectors. A negative impact of innovation on employment, associated with a strong skill bias effect, characterizes the financial services and the advertising industries. On the whole, innovation activities seem to have had a positive impact on employment in services in the period covered by the survey (1993-95).

The studies reviewed in Section 5 of this article focus mainly on the relationship between organizational and technological innovation and its impact on employment at the firm level, in particular with regards to the distribution of the workforce qualifications and skills. Therefore, they do not establish whether these innovations lead to an absolute reduction of both the skilled and the unskilled workforce at the industry and the economy level. The chapter by Askenazy aims to determine the macro consequences of re-organization and computerization on employment and their skill bias. To this purpose, the analysis is concentrated on American manufacturing since 1980, and uses longitudinal data at 4-digit industry level. As detailed information on re-organization is not available, to determine whether an industry was re-organized the author exploits the positive correlation between the adoption of innovative practice and the rate of occupational injuries. Indeed, the introduction of new manufacturing methods entails a learning phase for the workforce during which workers are more vulnerable to occupational health hazards.

Thus, Askenazy can determine whether an industry underwent re-organization by examining the annual rate of increase in the number of occupational injuries. A first result, obtained by considering the total number of workers, is that computerization has no apparent impact on employment in manufacturing, while re-organization resulted in a 1 per cent decrease in employment per year. When the share of non-production workers over total employment is used as the dependent variable in the econometric analysis, the estimates indicate that re-organization is not biased against production employment, although it reduced non-production labor starting in 1986. Computerization, on the other hand, led to opposite results, as it appears to be strongly biased against production workers.

While the Vivarelli and Pianta book is primarily focused on the link between technological change and employment, the Petit and Soete volume presents a somewhat broader perspective on the same question by examining it from an Institutionalist viewpoint. Given the variety of contributions, the present work reviews only those chapters that are closely related to its main theme. In the introduction to the volume, the editors focus on the underlying structural nature of the employment crisis in Europe. They identify four sources of structural change: aggregate (global level) change, sectoral change, organizational change, and institutional change. Each of the subsequent chapter deals with one of these four factors.

In the first chapter, Chris Freeman attempts to connect long-run employment problems to technological change. He identifies "triad" countries, the U.S., Japan, and Europe. Freeman asserts that ICT constitutes an important general purpose technology (GPT), since it affects almost all functional areas of firms in almost every industry. After examining patterns of technological investment and employment patterns in these countries, he offers several policy recommendations. These are greater cooperation between Europe, Japan, and the U.S., in an effort to enhance aggregate demand and to reform international institutions to implement a global Keynesian strategy.

In the following chapter, Von Tunzelman and Efendioglu strike a somewhat similar note. They present econometric evidence based on national-level data for the post-war period. They find that diminishing returns are pervasive, in contrast to "new growth" theories which devote considerable attention to the existence increasing returns to technological and human capital. Another key result of their study is that policymakers should give similar weight to both demand and supply factors, a consistent theme throughout the edited volume.

Petit's chapter is devoted to a comprehensive analysis of Europe's long-run unemployment problem. The author notes that there are four theories used to explain unemployment: 1) imperfect labor markets, 2) aggregate demand delinquencies, 3) technological unemployment, and 4) increasing mismatches in product markets. He asserts that it is more important to focus on the ability of economies to adjust to structural changes. Petit identifies three major structural changes that could have had significant employment effects. The first is technological change in the form of ICT. Another critical trend is internationalization and the growing importance of trade flows. There have also been changes in nature of trade (e.g., more trade in services) and liberalization in global financial markets. Finally, he alleges that there has been "tertiarization," or rapid growth in business services. This chapter is highly useful because it stresses the linkages among these numerous structural changes across industries and nations.

Schettkat and Russo focus on the underlying economics of structural change, especially the role of product demand. This is a critical point that is often ignored in policy analysis. Specifically, they note that the effects of technological change and productivity growth on employment will depend on the price elasticity of demand, the nature of the industry, and demand-side reactions. If product demand is price-inelastic then the labor-saving element of productivity growth is dominated by the expansionary effect. Consistent with Siegel and Griliches (1992), Morrison and Siegel (1997), and ten Raa and Wolff (2001), the authors find that outsourcing is not a critical factor in explaining changes in productivity.

The next five chapters of the Petit and Soete volume examine the relationship between technical change and organizational change. We consider this topic in the two following sections.

4 - THE RELATIONSHIP BETWEEN TECHNOLOGICAL CHANGE AND ORGANIZATIONAL CHANGE

Many economists who have studied SBTC ignore the role of organizational change in the implementation of new technologies. In recent decades, many manufacturing firms have adopted new technologies, such as computer-aided design (CAD), computer-aided manufacturing (CAM), computer numerical control (CNC), and just in time production (JIT) systems. Implementation of these technologies can have a dramatic impact on the work environment since they may simultaneously result in organizational restructuring, e.g., downsizing (labor-saving innovations), retraining of the remaining workforce ("skill-upgrading"), and changes in job responsibilities resulting from integration across the functional areas of business (marketing, manufacturing, R&D, accounting/finance, logistics, purchasing, and product design). In this section, we look at the links between technological and organizational change by reviewing some recent theoretical contributions from neoclassical economics, where the elements of such a relationship are seen as complementary. Such a view can be found also within an array of well-established conceptualizations from the management and strategy literature, which we also discuss. In the next section, using this combined theoretical analysis as a backdrop, evidence is presented showing how the effects of technological progress on employment are mediated by firm level factors. This bears important policy implications, which are presented in the concluding section.

IV.I – A theoretical framework for the analysis of the relationship between technological and organizational change.

Since the publication of *Strategy and Structure* (Chandler, 1962), organizational scholars have examined the fit between a firm's strategy (including its technology strategy), structure, and managerial processes. They have also stressed the difficulties of achieving an excellent fit, especially if organizational design must be modified to adapt to environmental change.

There is abundant anecdotal evidence to suggest that organizational change and technological/environmental change are closely associated. More specifically, it appears that technological innovations often stimulate provocative, efficiency-augmenting organizational innovations. Besanko et al. (2000) assert that the evolution of the hierarchical firm at the beginning of the 20th century was a direct consequence of improvements in the U.S economic infrastructure, especially in transportation (railroads) and communications (telephone). The related shift from the U-form to the M-form led to the emergence of a class of professional managers, thereby leading to the substitution of the *visible* hand of management for the *invisible* hand of the market (Chandler, 1977). This was also accompanied by changes in organizational practices, most notably, the implementation of Frederick Taylor's principles of "scientific management."

The shift from mass production to 'lean manufacturing' that started in the late twentieth century presents qualitatively similar characteristics. Indeed, the use of flexible machine tools and programmable, multitask equipment is often associated with new product and organizational strategies and workforce management policies (Milgrom and Roberts, 1990).

Neoclassical economics has largely overlooked the relationship between technological change, a firm's internal organization, and its competitive strategy. More recently, the analysis of strategy and structure has attracted the interest of economists. Indeed, industrial organization provides the theoretical foundation for the analysis of strategy formulation, while transaction cost economics, agency theory, and the incentive and contract theories have addressed several implementation issues, such as organizational structure and design and managerial practices.

Nonetheless, the literatures on strategy and structure have developed separately in economics and management. It is clear that insights from economics alone are not sufficient to fully explain organizational structure and design, competitive behaviour, and the firm's response to technological change. As a result of this gap, several interesting books have been published recently that integrate advances in economic theory with contributions from the management literature (Milgrom and Roberts, 1992; Besanko et al, 2000; Brickley et al, 2001).

Brickley et al. (2001) provide a framework that identifies three critical aspects of *organizational architecture:* the assignment of decision rights within the company, the methods of rewarding individuals and the structure of systems to evaluate and monitor the performance of both individuals and business units. The first aspect is concerned with the question of whether decision-making should be centralized or decentralized. The resolution of this issue is strongly related to certain human resource management practices, such as the use of worker teams and employee empowerment, as well as the extent to which a firm engages in vertical integration. The second aspect refers to compensation and incentive packages. The third issue relates to the degree to which the firm can ensure that the actions of workers and managers are aligned with the company's overall objectives.

All three aspects are mutually interdependent: metaphorically they could be thought of as the "three legs of a stool", that is, changing one without changing the other is unlikely to engender a well-balanced and functional organization. Such an approach could be further developed to study the relations between a firm's organizational architecture, its strategy and its business environment. These are summarized in Figure 1, which demonstrates how strategy and organizational structure are mutually dependent.

Chandler's thesis that "structure follows strategy" is illustrated by changes in the organizational structure of many large U. S. companies at the beginning of the 20th century. The changes in structure were driven by changes in strategy that, in turn, were associated with changes in external conditions that these firms encountered. However, as the two-headed arrow in Figure 1 indicates, strategy can also be influenced by organizational architecture.

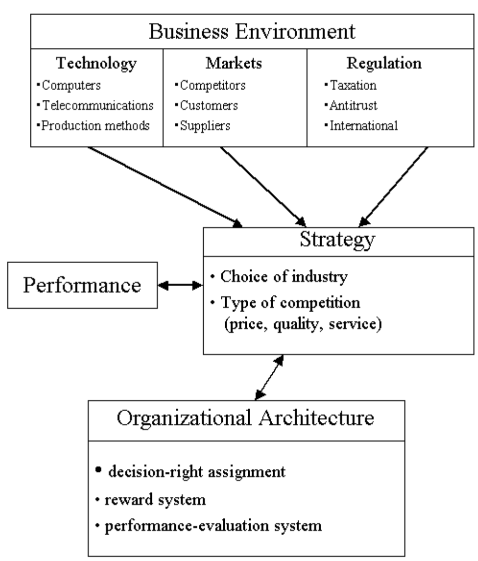

Figure 1 – A framework for the relationships between business environment, strategy and organizational architecture.

Indeed, structure can also be seen as the formalization of decision-making routines, which determine how organizations function (Nelson and Winter, 1982). Routines evolve as the firm develops in response to environmental changes. At the same time, prevailing routines constrain the process of learning and adaptation that is required after changes in the external environment. Indeed, local search implies that alterations will be first sought in the neighbourhood of existing routines. In this sense, strategy may also follow structure. An important implication is that, because changes in routines are difficult to implement, a firm's adaptability to changing circumstances may be impaired, leading to the prediction that both large-scale strategic change and comprehensive restructuring will be rarely undertaken. This has important performance consequences, as it has been observed that the passage from mass production to lean manufacturing may necessitate a drastic overhaul of the existing organization (Brynjolfsson and Hitt, 2000; Milgrom and Roberts, 1990 and 1995). Indeed, these authors argue that introducing computer-based machinery without organizational change may not engender significant productivity gains, as any benefits of computerization are more than offset by the losses associated with the mismatch between the firm's current organizational practices and its new production methods.

An excellent example of a mismatch is provided in Milgrom and Roberts (1995): "General Motors spent some $80 billion during the 80's on robotics and other capital equipment … It did not, however, make any serious adjustments in its human resource policies, its decision systems, its product development processes, or even in its basic manufacturing procedures. The result was that those billions of dollars were largely wasted: GM …had assembly lines that should have been the most flexible in the world but that produced only one single model (p.194)". Brynjolfsson, Renshaw and Van Alstyne (1997) illustrate the perverse effects of an introduction of flexible computer integrated manufacturing by a large U.S. medical products manufacturer. They observe that the organizational inertia was so strong that production line workers used the new equipment's flexibility in order to get it to work much like the old machines! In sum, anecdotal evidence based on case studies of firms using IT to transform their production process justifies the "systemic" approach entailed in the "three-legged stool" metaphor, requiring consistency in the changes between the components of the organizational architecture (Brynjolfsson and Hitt, 2000).

The reluctance of economists to analyze organizational change is based on their disinclination to go inside the *black box* and examine managerial practices. This dearth of theoretical analysis was also partly due to the analytical intractability of a plausible model of internal organization that would incorporate numerous interrelated choice variables and nonconvexities, such as the decision to empower employees.

In two influential papers, Milgrom and Roberts (1990 and 1995) assert that the formal notions of complementarity and supermodularity provide a promising way to understand the relationship among various elements of an organization's strategy and structure and the associated "system effects". The notion of complementarity is to identify two policies or inputs or activities, such that doing more of one increases the return to doing more of the other. The supermodularity of profit and cost functions, defined over a set of complementary choice variables, does not impose any restrictions to any particular functional form or to convexity, smoothness and divisibility assumptions.

In their influential 1995 paper, Milgrom and Roberts outline a model that involves twelve choice variables and two exogenous parameters to address a range of human resource management policies that have been identified as important aspects of the modern, lean manufacturing system. The interconnections among the variables are depicted in Figure 2. The two exogenous parameters, _ and _, represent, respectively, (1) the cost of computer-aided design (CAD) equipment, which in turn affects the costs of achieving a particular level of design efficiency, and (2) the cost of computer-numeric controlled machinery and robotics (CAM), which in turn influence the costs of achieving a given level of flexibility in the production system.   This method allows for analysis of the systemic effects initiated by a change in the exogenous parameters. They find that increases in the efficiency of CAD and CAM will lead to, *inter alia*: more cross training, use of teams and pay-for-skill and greater autonomy for workers (p.199).

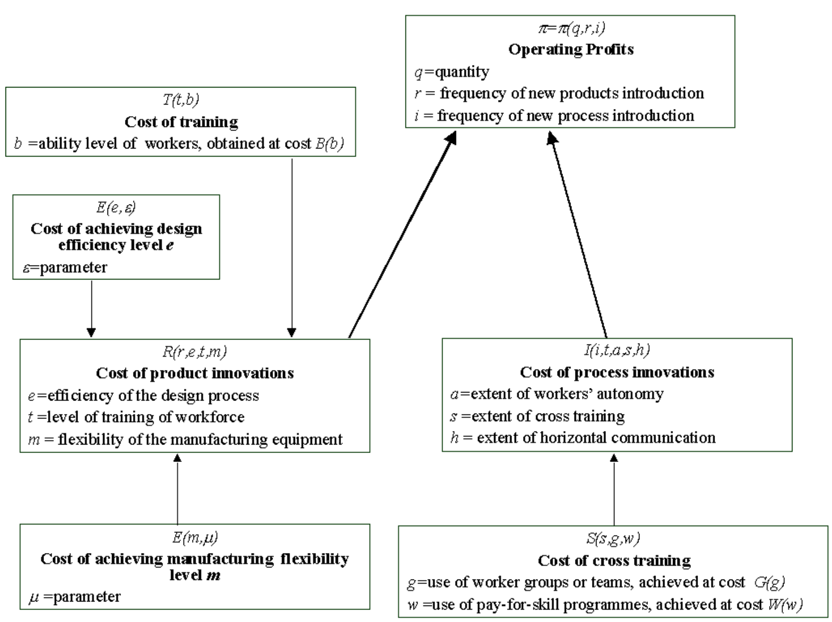

Figure 2 – A graphical representation of the model in Milgrom and Robert (1995)

The supermodularity approach bears two important implications. First, identifying a single element of the organizational architecture and trying to implement it in another system without the original complementary features is unlikely to yield a positive outcome. This is consistent with the analysis in Marengo *et al.* (2000), who observe: "…introducing some routines, practices or incentive schemes that have proven superior in another organizational context could prove harmful in a context where other elements are not appropriately tuned (p. 759)". Second, it is unreasonable to think that the introduction of, say, a flexible manufacturing system and the associated organizational changes could be achieved without the active role of central coordination that fully takes into account the complementarity between the firm's organizational components. The implications of both these points are clearly illustrated in the case study of the Lincoln Electric Company discussed in Milgrom and Roberts (1995).

5 - EVIDENCE ON THE COHERENCE BETWEEN TECHNOLOGICAL AND ORGANIZATIONAL CHANGE

Consistent with the theoretical arguments advanced in the previous section, several recent studies have examined the relationship between technological and organizational change. Scholars who have analyzed the impact of IT on worker or firm performance have come to realize that investment in this technology is often accompanied by dramatic changes in the work environment. For instance, Siegel, Waldman, and Youngdahl (1997) examined the effects of the adoption of advanced manufacturing technologies on human resource management practices, including proxies for employee empowerment, such as training, changes in job responsibilities, new career opportunities, and enhanced employee control. They find a strong association between the implementation of certain types of technologies and enhanced employee empowerment. Unfortunately, they could not segregate these effects for unionized and non-unionized firms.

Bresnahan, Brynjolfsson and Hitt (2002) also provide evidence on the relationship between technological change, organizational change, and performance. They analyze the effects of declining information technology (IT) prices, increased use of IT and the increase in the relative demand for skilled labor. The authors hypothesize that, in order to implement new technologies successfully, firms must decentralize decision-making and adopt other “high performance” workplace practices. The latter refer to an increased reliance on teams and quality circles, where employees can decide the pace and method of work. To test these theories, the authors estimate three variants of a regression model with IT demand, human capital investment, and “productivity” (actually, value added), as dependent variables. They find that proxies for workplace organization and human capital are strong predictors of the demand for IT, but not other types of physical capital. This result supports the notion that there is complementary between IT, organizational change and human capital. Similarly, firms with higher levels of investment in human capital, as measured by a greater emphasis on selection, appraisal, and training of workers employees, tend to have higher levels of IT investment and more decentralized work organization.

Finally, the authors estimate a three factor Cobb-Douglas production function, including labor, non-computer capital, and computer capital. Such an estimation approach is aimed at circumventing the difficulty in obtaining data on the change in the product and service quality and the invention of new products and services. However, if changes in the product and service mix are complementary to IT, human resource policies and human capital, and firms can charge a price premium and/or sell more units of their new products, then differences in productivity will reflect differences in the levels of IT, human capital and workers' empowerment. To further explore the complementarity hypothesis, the authors include numerous interaction terms in the econometric model. As predicted, the interaction of computer capital and the proxy for decentralization is found to be strongly positive and highly significant. They also show that decentralized firms generate a higher return (marginal product) on investments in computers.

In order to assess complementarities in a production function framework, it is necessary to assume the existence of adjustment costs in the implementation of complementary strategies (see Caroli and Van Reenen, 2002). Adjustment costs are relevant because while it may be easy to acquire and install IT equipment, a firm may have great difficulty implementing required complementary organizational changes to achieve a fit among all its organizational architecture components. Thus, adjustment costs lead to variation across firms in the use of IT, its organizational complements, and the resulting product mix. Indeed, absent such costs, firms' optimizing behavior would take into account the potential complementarities and remove the identifying variation from the production function regressors.

The presence of adjustment costs can be directly related to some of the theoretical arguments discussed in the previous section. Nelson (1997) asserts that it is important to analyze the antecedents and consequences of these adjustment costs. He states "…the practiced routines that are built into an organization define a set of things an organization is capable of doing confidently (pg. 263)." Nelson argues that developing new competencies may be possible only if practiced routines are changed. Failing to do so will engender adjustment costs. However, these can arise even when the firm tries to change its routines in accordance with its new strategic goals. Indeed, established routines serve as an organizational truce as they help to reduce intra-organizational conflict (Coriat and Dosi, 1998; Douma and Schreuder, 1998).

The bargaining process that strategic change elicits among members of an organization inevitably carries "adjustment" costs, an instance of which are *influence costs* (Milgrom and Roberts, 1992). It appears that the factors that are most likely to affect the magnitude of adjustment costs are 1) the extent to which new core competencies differ from existing ones; 2) whether organizational culture is conducive to change, and 3) whether there is the right balance between decentralization and coordination of activity.

Finally, Bresnahan, Brynjolfsson and Hitt (2002) present evidence on the effects of information technology on the work environment, based on a survey of managers. They find that computer use is associated with an increase in worker autonomy and management's need and ability to monitor workers, which induces managers to increase investment in human capital. These results are consistent with evidence presented in Siegel, Waldman, and Youngdahl (1997). The authors conclude that "managers are clearly thinking in terms of the relationship between technological progress and skill demand when they invest in human capital, organizational decentralization and IT (p. 369)".

We now present some additional empirical evidence on the relationship between technological and organizational change, based on the 1998 Mediocredito Centrale Survey of Italian manufacturing firms (see Piga (2002), Piva and Vivarelli (2002) and Piga and Vivarelli (2003) for a comprehensive description of this survey). Table 2 presents some simple descriptive statistics. Note that slightly less than a third (32.4%) of the firms that introduced a product or process innovation also implemented an organizational change during the sample period. This is actually a lower bound on the incidence of organizational change, since there is a possibility that other innovative firms had already introduced managerial innovations in a previous period. This evidence also suggests that Italian managers perceive the need to achieve a fit between their firms' strategies and organizational design. The figures reveal that adjustment costs may be preventing some of the innovative firms from fully exploiting the advantages of achieving such a fit.

On a related note, the results presented in Table 2 suggest that the probability of implementing an organizational change in the aftermath of a technological change increases with firm size. This is consistent with evidence discussed in previous sections of the paper, since system effects spawned by technological change could have wider repercussions within a larger, more sophisticated organizational structure. Hence, there may be a stronger need to fine-tune in large firms, in order to achieve coherence among of all the organization's parts.

6 – SYNTHESIS AND CONCLUSIONS

In this section, we synthesize and integrate the policy recommendations contained in the edited volumes, along with evidence discussed in previous sections of the paper. Pianta and Vivarelli propose three directions for policy, in order to address market failures hindering the proper functioning of compensation mechanisms: a new macroeconomic policy, industrial policy, and a targeted innovation policy. We focus our attention on the last two initiatives.

According to the authors, industrial policy should try to favor a "process of structural change" towards sectors with "high growth and employment potential, high network externalities and high capacity for learning and development and adoption of product innovations." Thus, Pianta and Vivarelli advocate a crucial role for active industrial policy that has been largely abandoned in many countries and substituted by competition policy. However, the latter can also play a critical role in fostering a more labor-intensive structure of the economy, by "opening up access for new producers in key areas, especially in services, where the established market structures and monopolistic rigidities prevent obtaining the full potential offered by new technologies."

Pianta and Vivarelli assert that there are four central features of an optimal innovation policy. First, it should focus on employment friendly innovations. Pecuniary and non-pecuniary incentives for innovation should be targeted to those activities that are more likely to lead to the creation of new products, rather than labor-saving new processes. However, financial support for the knowledge creation process associated with R&D should be preserved and favored with respect to subsidies for the acquisition and introduction of innovation-related equipment that tends to substitute labor. Second, steps should be taken to facilitate the realization of the full potential of ICT that is hindered by "the mismatch and the lack of coordination between technological, organizational, institutional and social innovations that are required for the successful emergence of a new technological paradigm". Third, introducing demand-pull policies focused on the users' needs would induce coherence of organizational, institutional and social innovations. For example, Pianta and Vivarelli suggest that "public policy should help create selected markets in new ICT products and advanced services, acting as an early consumer and intelligent user". Indeed, the experience gained by public institutions adopting ICT products that often operate under different standards, may provide crucial information for enterprises and induce them to adopt the winning technology, thereby sparing them the cost of experiment to assess which technology is better suited to their needs. Fourth, strategies aimed at implementing a ‘learning society’ may prove useful not only in augmenting the stock of human capital that is required to maintain a steady flow of innovations in the economy, but also in preventing a mismatch between skills supplied and skill demanded in the labor market.

Given the uncertainty regarding technological developments, policies should be aimed at providing firms with the tools they require to manage and potentially, overcome such uncertainty. Shaping working life in such a way that it gives the opportunity for continuous learning is conducive to an innovative organization where each member, at any level of hierarchy, understands the value-enhancing implications of developing products and of innovating processes. Creating and maintaining a life-long learning society is not an easy task because it entails a transformation of the relationships between working life and public and private educational institutions. However, as Lundgren suggests in his essay in Vivarelli and Pianta’s volume, this is not a “…reason for waiting…[because] there are measures that can be taken immediately, whether we consider the individual, the unions, the employers or the politicians”. This is particularly relevant in the light of the evidence on the complementarity between technological and organizational change. While technology alone does not seem to bring about significant and long-lasting productivity enhancements, its combined effect with organizational change involving such human resource management practices as additional training, new job responsibilities and employees’ empowerment, has been found to benefit those firms that exploited the complementarity between human capital, organizational decentralization and ICT.

As discussed in the Petit and Soete volume, we must also not lose sight of institutional and structural changes that have occurred in conjunction with technological and organizational change, especially within the European Union. According to Petit and Soete, the key institutional and structural factors are changes in the organization of working time that enhance the quality of work life (e.g., conditions of part-time work), the development of national innovation systems and its concomitant emphasis on the importance of institutions (e.g., universities), and the evolution of the welfare state (i.e., the social "safety net"). These factors are especially relevant in the context of the debate on labor market flexibility. These must also be taken into consideration by organizations that are adjusting to technological change.

To summarize, the foregoing discussion has emphasized how the mainstream literature on SBTC has largely overlooked two important elements in the relationship between technological change and employment, i.e., the possibility of technological unemployment and the complementarity between a firm's organizational architecture and its business environment. Both elements are thoroughly discussed in the two books by Vivarelli with Pianta and Petit with Soete.

Furthermore, it has been argued that while recent theoretical advancements in a neoclassical spirit explicitly consider 'system effects' at the firm level, a better understanding of the complementarity between organizational and technological change can be obtained by extending the neoclassical paradigm so as to include contributions from less mainstream theoretical approaches such as evolutionary economics. Indeed, this combined approach may provide a rationale for empirical investigations that would appear unfounded if seen from a purely neoclassical economics perspective.

Finally, acknowledging a complementary relationship among technological, human, and organizational capital requires public policies that promote life-long learning in the workplace, and, more generally, the implementation of a 'learning society'. Developed and developing countries alike will have to achieve such goals, if in the future they want to enjoy economic growth accompanied by job creation.

Specifically, this implies that nations should also play a leading role in addressing technology-related skill deficiencies in the workforce. This can be achieved in several ways. One is to provide training and skills development or at least, to encourage state-run educational institutions to shift their priorities accordingly. Another approach is to provide incentives to firms to engage in such training themselves, through tax policy or through subsidies.

As noted in our discussion of the two edited volumes, it appears that the magnitudes of the market failures are sufficiently high that the public sector in an individual country alone cannot effectively overcome them. Thus, public-private partnerships might be useful for providing financial capital to stimulate investment in technology and for enhancing the development of human capital to facilitate implementation of the new technologies. These policy interventions should be targeted to reduce negative effects on workers and firms associated with adjusting to new technologies.

Table 1: Some Recent Empirical Studies of Skill-Biased Technological Change Involving ICT Investment

Author(s)	Methodology	Country	Level of Aggregation	Indicators of Technological Change	Measures of Labor Input	Results
Bartel and Sicherman (1999)	Estimation of wage equations	USA	Worker Data (NLSY) Matched to Industry-Level Data	Expenditures on Computers, R&D	Nonproduction and Production Workers	Positive Correlation Between Wages and Proxies for Technological Change, Which is Stronger for Nonproduction Workers than for Production Workers; The Wage premium is Attributed to the Greater Demand for Ability in Industries Experiencing Technological Change
Haskel (1999)	Regressions of Changes in Relative Wages of Skilled and Unskilled Workers on Computers	UK	3-digit SIC Industry-Level	Dummy Variable Denoting Whether a Plant Introduced New Equipment Based on Microchip Technology	Skilled and Unskilled Workers	Positive Correlation Between Relative Wages and Computers; Wage Premium for Skill Rose by 13% in the 1980s in the U.K.; Computers Account for About half of This Increase
Haskel and Heden (1999)	Regressions of Changes in Wage Bill Share for Four Classes of Workers on Computers and R&D	UK	Plant and Industry-Level	Expenditures on Computers, R&D;	Proportion of Firms in Sector Using Computers in Production Process Non-manual and Manual Workers Split Into Skilled and Unskilled Categories	Positive Correlation Between the Relative Wages of Skilled Non-manual Workers and Computers (also R&D); Computerization Reduces the Demand for Manual workers (Both Skilled and Unskilled Workers)
Dunne, Haltiwanger, and Foster (2000)	Regressions of Non-Production Worker Share on Computers	USA	Plant-Level	Computer Investment Per Worker	Non-production and Production Workers	Positive Association Between Non-production Worker Share and Computers, Which Appears to Be Growing Over Time; Skill-Biased Technological Change Also Appears to be Associated With Greater Dispersion in Wages and Labor Productivity (Across Plants) Over Time

Author(s)	Methodology	Country	Level of Aggregation	Indicators of Technological Change	Measures of Labor Input	Results
Morrison Paul and Siegel (2001)	Dynamic Cost Function Estimation with "High Tech" Capital	USA	4-digit SIC Industry-Level	Computer Capital and R&D	Four Types Of Workers, Classified by Level of Education	Computers and R&D Reduce the Demand for Workers Without a College Degree and Increase the Demand for Workers with at least Some College. Trade has a Strong Indirect Impact on the Demand for Less Educated Workers, because it Stimulates Additional Investment in Computers
Siegel (1999)	Regressions of Levels and Changes in Employment Shares (For 6 Classes of Workers) on Dummy Variables for Technology Adoption	USA	Firm-Level	Adoptions of 12 Types of Advanced Manufacturing Technologies (AMTs), Which Are Grouped Into Two Classes: "Linked" vs. Integrated AMTs	Six Classes of Workers (Managerial & Supervisory, Technological and Professional, R&D, Clerical & Administrative, Direct Labor and Supporting Personnel, and Other)	Technology Adoption is Associated With Shifts in Labor Composition in Favor of Highly Educated Workers and Greater Employee "Empowerment"; The Magnitudes of the "Skill-Bias" and Empowerment Effects May Depend on the Type of Technology that is Implemented

Table 2
Incidence of Product, Process and Organizational Innovations among 4405 Italian Manufacturing Firms

		Has the firm introduced organizational or managerial innovations related to the introduction of a **product** innovation?		Total
		No	Yes	
Has the firm introduced **product** innovations?	No	3064		3064
	Yes	906 (67.6%)	434 (32.4%)	1340 (100%)
Total		3970	434	4404

		Has the firm introduced organizational or managerial innovations related to the introduction of a **process** innovation?		Total
		No	Yes	
Has the firm introduced **process** innovations?	No	1432		1432
	Yes	2032 (68.4%)	941 (31.6%)	2973 (100%)
Total		3464	941	4405

Number of firm's employees	Has the firm introduced organizational/managerial innovations related to the introduction of a **product** innovation?		Total	Has the firm introduced organizational/managerial innovations related to the introduction of a **process** innovation?		Total
	No	**Yes**		**No**	**Yes**	
11-20	1099 (96%)	46 (4%)	1145	989 (86.5%)	154 (13.5%)	1143
21-50	1551 (92.7%)	122 (7.3%)	1673	1343 (80.2%)	331 (19.8%)	1674
51-250	967 (86.2%)	155 (13.8%)	1122	833 (74.1%)	291 (25.9%)	1124
251-500	214 (79%)	57 (21%)	271	195 (71.1%)	79 (19.9%)	274
>500	139 (72%)	54 (28%)	193	104 (54.7%)	86 (46.3%)	190
Total	3970 (90.1%)	434 (9.9%)	4404	3464 (78.6%)	941 (21.4%)	4405

Source: Mediocredito Centrale.

REFERENCES

Akerlof, G. (1983), 'Loyalty Filters', *American Economic Review*, 73: 54-63.

Bartel, A.P. and Lichtenberg, F.R. (1987) 'The comparative advantage of educated workers in implementing new technology,' *Review of Economics and Statistics*, 69: 1-11.

Bartel, A.P. and Sicherman, N. (1999). 'Technological change and wages: An interindustry analysis," *Journal of Political Economy*, 107: 285-325.

Bentolila, S. and Martin, J. (1994) 'Labour Market Flexibility and Wages: Lessons From Spain', *Economic Policy*, 18, 53-100.

Berman, E., Bound, J. and Griliches, Z. (1994) 'Changes in the demand for skilled labor within U.S. manufacturing industries: Evidence from the annual survey of manufacturing,' *Quarterly Journal of Economics,* 109: 367-397.

Bertola, G. and Ichino, A. (1995) 'Crossing the River: A Comparative Perspective on Italian Employment Dynamics', *Economic Policy*, 21, 359-420.

Besanko, D., Dranove, D., and Shanley, M. (2000), *Economics of Strategy (2nd. Edition)*, John Wiley & Sons, Inc., New York.

Bresnahan, T.F., Brynjolfsson, E. and Hitt, L.M. (2002) 'Information Technology, Workplace Organization, and the Demand for Skilled Labor: Firm Level Evidence,' *Quarterly Journal of Economics,* 117, p. 339-376.

Brickley, J. A., Smith, C. W. and Zimmerman, J. L. (2001) *Managerial Economics and Organizational Architecture*, McGraw-Hill, New York, N.Y.

Brynjolfsson, E. and Hitt, L.M., (2000) 'Beyond Computation: Information Technology, Organizational Transformation and Business Performance', *Journal of Economic Perspectives,* 14(4), Fall, p. 23—48.

Brynjolfsson, E., Renshaw, A. and Van Alstyne, M., (1997) 'The Matrix of Change', *Sloan Management Review,* Winter.

Caroli, E. and Van Reenen, J, (2002) 'Skill-Biased Organizational Change: Evidence from A Panel of British and French Establishments,' *Quarterly Journal of Economics,* 116, 1449-1492.

Chandler, A. D., (1962), *Strategy and Structure*, MIT Press, Cambridge, MA.

Chandler, A. D., (1977) *The Visible Hand*, Belknap, Cambridge, MA.

Coriat, B. and Dosi, G. (1998), 'Learning How to Govern and Learning How to Solve problems: On the Co-evolution of Competences, Conflicts, and Organizational Routines,' in *The Dynamic Firm: The Role of Technology Strategy, Organization, and Regions*, (A.D. Chandler, P. Hagstrom, and O. Solvell (eds.), Oxford University Press, Oxford and New York.

Douma S., and Schreuder, H., (1998) *Economic Approaches to Organizations*, Prentice Hall Europe, Hemel Hempstead, UK.

Dunne, T., Haltiwanger, J., and Foster, L., (2000) 'Wages and Productivity Dispersion: The Role of Computer Investment,' *NBER Working Paper #7465.*

Evangelista, R., Perani, G., Rapiti, F. and Archibugi, D. (1997) 'Nature and Impact of Innovation in Manufacturing Industry: Some Evidence from the Italian Innovation Survey'. *Research Policy*, **26**, 521-536;

Haskel, J. (1999), 'Small Firms, Contracting-Out, Computers and Wage Inequality: Evidence from U.K. Manufacturing,' *Economica*, 66, 1-21.

Haskel, J. and Heden, Y. (1999) 'Computers and the demand for skilled labour: Industry and establishment-level panel evidence for the U.K.,' *Economic Journal*, 109: 68-79.

Link, A.N. and Siegel, D.S. (2002). 'Unions and Technology Adoption: A Qualitative Analysis of the Use of Real Time Control Systems in U.S. Coal Firms,' *Journal of Labor Research*, 23, 617-632.

Marengo, L., Dosi, G., Legrenzi, P., and Pasquali, C., (2000), 'The Structure of Problem-solving knowledge and the structure of Organizations', *Industrial and Corporate Change,* 9(4), p. 757—788.

Metcalfe, S. (1995) 'The Economic Foundations of Technology Policy: Equilibrium and Evolutionary Perspectives'. In Stoneman, P. (ed) *Handbook of the Economics of Innovation and Technological Change.* Blackwell, Oxford UK & Cambridge USA.

Milgrom, P. and Roberts, J. (1990) 'The Economics of Modern Manufacturing: Technology, Strategy, and Organization,' *American Economic Review*, 80: 511-528.

Milgrom, P. and Roberts, J, (1992), *Economics, Organization and Management*, Prentice Hall International, Englewood Cliffs, NJ.

Milgrom, P. and Roberts, J. (1995) 'Complementarities and Fit: Strategy, Structure, and Organizational Change in Manufacturing,' *Journal of Accounting and Economics*, 19(2-3): 179-208.

Morrison, C. and Siegel, D. (1997), 'External Capital Factors and Increasing Returns in U.S. Manufacturing,' *Review of Economics and Statistics*, 79(4): 647-654.

Nelson, R. R., (1997), 'Why do Firms Differ, and How does it matter?'. In Foss, N. J. (ed.), *Resources Firms and Strategies*, Oxford, UK: Oxford University Press.

Nelson, R.R. and Winter, S.G. (1982) *An Evolutionary Theory of Economic Change*, Harvard University Press, Cambridge, MA.

Oulton, N. (1995) 'Supply Side Reform and U.K. Economic Growth: What Happened to the Miracle', *National Institute Economic Review*, November 1995, 154, 53-70.

Paul, C.J.M. and Siegel, D.S. (2001) 'The Impacts of Technology, Trade, and Outsourcing on Employment and Labor Composition', *Scandinavian Journal of Economics*, 103: 241-264.

Petit, P. and Soete, L. (ed.) (2001) '*Technology and the Future of European Employment',* Edward Elgar, Cheltenham, U.K.

Piga, C. A. (2002), 'Debt and Firms' Relationship: the Italian Evidence', *Review of Industrial Organization,* 20, 267—282.

Piga, C.A. and Vivarelli, M. (2003), 'Sample Selection in estimating the determinants of cooperative R&D', *Applied Economics Letters,* 10, 243-246.

Piva, M. and M. Vivarelli (2001), 'The Skill Bias in Italy: a first report', *Economics Bulletin*, 15 (2), 1-8, URL: http://ww.economisbulletin.com/2001/volume15/EB-01O30002A.pdf

Piva, M. and M. Vivarelli (2002), 'The Skill Bias: comparative evidence and an econometric test', *International Review of Applied Economics*, 16, 347-357.

Potter, E.E. (2001), 'Labor's Love Lost: Changes in the U.S. Environment and Declining Private Sector Unionism', *Journal of Labor Research* 22, 321-334.

Shleifer, Andrei and Lawrence H. Summers (1987) 'Breach of Trust in Hostile Takeovers,' in *Corporate Takeovers: Causes and Consequences*, Chicago: University of Chicago Press, 1987.

Siegel, D.S. (1999) *Skill-Biased Technological Change: Evidence from a Firm-Level Survey*, Kalamazoo, MI: W.E. Upjohn Institute Press.

Siegel, D. and Griliches, Z. (1992), 'Purchased Services, Outsourcing, Computers, and Productivity in Manufacturing,' in *Output Measurement in the Service Sector*, (Zvi Griliches, ed.) Chicago: University of Chicago Press, pp. 429-458.

Siegel, D.S., Waldman, D., and Youngdahl, W. (1997). 'The Adoption of Advanced Manufacturing Technologies: Human Resource Management Implications', *IEEE Transactions on Engineering Management*, 44, 288-298.

ten Raa, T. and Wolff, E.N. (2001), 'Outsourcing and the Recovery of Manufacturing Productivity Growth in the 1980s,' *Journal of Productivity Analysis*, 16, 149-165.

Troske, K. (1998), 'The Worker Establishment Characteristic Database'. In Haltiwanger, J., Lane, J., Spletzer, J., Theeuwes, J. and Troske, K. (eds.), *Labor Statistics: Measurement Issues,* Chicago: University of Chicago Press for the NBER., 371-403.

Vivarelli, M. (1995), *The Economics of Technology and Employment: Theory and Empirical Evidence*, E. Elgar, Aldershot (UK).

Vivarelli, M. and Pianta, M., eds. (2000) *The Employment Impact of Innovation. Evidence and Policy*, Routledge, London and New York.