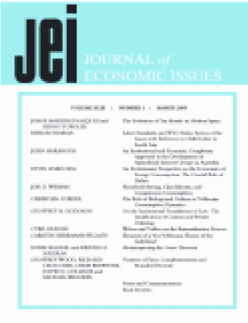

Journal of Economic Issues

Routledge
Taylor & Francis Group

ISSN: 0021-3624 (Print) 1946-326X (Online) Journal homepage: http://www.tandfonline.com/loi/mjei20

Innovation, Employment and Skills in Advanced and Developing Countries: A Survey of Economic Literature

Marco Vivarelli

JOURNAL OF ECONOMIC ISSUES
Vol. XLVIII No. 1 March 2014
DOI 10.2753/JEI0021-3624480106

Innovation, Employment and Skills in Advanced and Developing Countries: A Survey of Economic Literature

Marco Vivarelli

***Abstract*:** I discuss the theoretical and empirical literature on the quantitative and qualitative employment impact of technological change. I also compare the relative explanatory power of competing economic theories, while detailing the macro, sectoral, and micro evidence on the issue with reference to advanced and developing economies. The main purpose of the paper is to offer a critical meta-analysis of both the theory and recent empirical achievements stemming from the relationship of technology and employment. More specifically, I draw some general conclusions about possible consequences of that relationship.

Keywords: employment, innovation, skill, skill-biased technological change, technology

JEL Classification Code: O33

Most new technologies are introduced to save labor. Yet, massive technological unemployment has not occurred since the first industrial revolution. However, at least in some historical periods, job losses due to innovation have been far from negligible, and the debate about technological unemployment has been periodically revived.

Indeed, the potential adverse effect of technological change on employment and the possibility of counterbalancing the initial displacement of jobs are old and controversial issues in economic thought. As J.B. Say ([1803] 1964, 87) put it, "[m] achines cannot be constructed without considerable labour, which gives occupation to

---

Marco Vivarelli is a professor of economics at Università Cattolica del Sacro Cuore, Piacenza and Milano (Italy). *This paper is based on a research project (RG-K1164 "Employment Generation, Firm Size and Innovation in Latin America: The Microeconometric Evidence") coordinated by the Science and Technology Division of the Inter-American Development Bank (IDB). A previous version of this paper was originally published as an IDB Technical Note, IDB-TN-351, and can also be found at www.iadb.org/publications/search.cfm?docType=Technical%20Notes. The Inter-American Development Bank Technical Notes encompass a wide range of best practices, project evaluations, lessons learned, case studies, methodological notes, and other documents of technical nature. The information and opinions presented in these publications are entirely those of the author, and no endorsement by the Inter-American Development Bank, its Board of Executive Directors, or the countries they represent, is expressed or implied by the author. Comments and suggestions by two anonymous referees and by Christopher Brown were particularly useful for improving and extending this paper. The usual disclaimers apply.*

the hands they throw out of employ." In historical terms, the fear of technological unemployment has always emerged in ages characterized by radical technological change. For instance, the striking response of the English workers to the first industrial revolution was the destruction of machines under the leadership of Ned Ludd, who lent his name to the anti-technology Luddite movement (Hobsbawm 1968; Hobsbawm and Rudé 1969).

On the other hand, since its inception, economic theory has pointed out the existence of economic forces that can spontaneously compensate for the reduction of employment due to technological progress. Referencing David Ricardo ([1821] 1951), the "working class opinion" faced the fear of being dismissed because of technical change. At the same time, the academic and political debate was mainly dominated by an ex-ante confidence in the market compensation of dismissed workers. "I have before observed, too," Ricardo wrote, "that the increase of net incomes, estimated in commodities, which is always the consequence of improved machinery, will lead to new saving and accumulation" (Ricardo [1821] 1951, 396).

It is interesting to observe that, mutatis mutandis, the present economic debate about the employment impact of innovation is still focused on those market compensation forces which can counterbalance the initial labor-saving effect of process innovation. Yet, recent economic analyses have also singled out two other important aspects of the relationship between technological change and employment. On one side, is the possible labor-friendly impact of product innovation, as opposed to process innovation, and, on the other side, is the potential "qualitative" effect of innovation (in terms of its skill bias), as opposed to the sole "quantitative" effect regarding potential displacement of workers.

In this paper, I critically discuss theoretical and empirical literature on the quantitative and qualitative employment impact of technological change. I also compare the relative explanatory power of the competing theories, while detailing the macro- and micro-evidence on the issue at hand. Indeed, my main goal is to articulate a critical meta-analysis of both economic theory and recent empirical achievements dealing with the employment impact of innovation. The final purpose is to reach some general conclusions about the nature and potential impact of the relationship between technology and employment.

The section that follows is devoted to the so-called "theory of compensation," a classical theory that is still the basis of current economic models that try to articulate the employment impact of innovation. In the light of classical taxonomy, section two of the paper presents a survey of the available empirical evidence regarding the relationship between innovation and employment at the macro-, sectoral-, and micro-level. Section three introduces literature on the so-called "skill-biased technological change." Section four focuses on developing countries (DCs). I conclude in section five.

Innovation and Employment: The Theory

According to microeconomic theory, technological change allows for the same amount of output with a lower amount of production resources, including capital and labor.

However, what economic textbooks present as technological change (that is either an upward movement of a short-term production function or a downward movement of the isoquant) is only the "direct" effect of innovation. Indeed, since its foundation, the economic discipline has tried to dispel all concerns about direct harmful effects of technological change pointing to both (i) market mechanisms acting to counterbalance the direct impact of process innovation, and (ii) job creating effects of product innovation as mitigating factors.

Thus, in the first half of the nineteenth century, (while the Luddites were destroying the new machines), economists put forward a theory which Karl Marx later called the "compensation theory" (Marx [1867] 1961, ch. 13, and Marx [1905–1910] 1969, ch. 18). This theory comprises different market compensation mechanisms that are triggered by technological change and can counterbalance the initial labor-saving impact of process innovation (for extensive analysis, see Petit 1995; Pianta 2005; Vivarelli 1995, chs. 2 and 3; Vivarelli and Pianta 2000, ch. 2).

The compensation theory has several components:

1. A compensation mechanism "via new machines": The same process innovations which displace workers in user industries also create new jobs in capital sectors where the new machines are produced (Say [1803] 1964).

2. A compensation mechanism "via decrease in prices": On one hand, process innovations involve the displacement of workers. On the other hand, these innovations lead to a decrease in the unit costs of production and, in a competitive market, this means decreasing prices. In turn, lower prices stimulate a new demand for products, and thus additional production and employment. This mechanism was singled out early on in the history of economic thought. As James Steuart ([1767] 1966, 256) put it:

> The introduction of machines is found to reduce prices in a surprising manner. And if they have the effect of taking bread from hundreds, formerly employed in performing their simple operations, they have that also of giving bread to thousands.

Indeed, the compensation mechanism "via decrease in prices" has been re-proposed many times in the history of economic thought, both by neo-classical economists at the beginning of this century (see Clark 1907, 270; Pigou [1920] 1962, 672) and by modern theorists (Dobbs, Hill and Waterson 1987; Hall and Heffernan 1985; Heffernan 1981; Neary 1981; Nickell and Kong 1989; Stoneman 1983a, chs. 11 and 12; for a detailed analysis of the hypotheses, procedures and conclusions of these models, see Vivarelli 1995, chs. 4 and 6).

3. A compensation mechanism "via new investments": In a world where competitive convergence is not instantaneous, innovative entrepreneurs can accumulate extra-profits in the gap of time between a cost decrease due to technical progress and a subsequent fall in prices generated by the former. These profits are invested and new productions and jobs are created as a result. Originally put forward by Ricardo ([1821] 1951), this mechanism was central in the German school's analysis (Lederer 1931; Lowe 1976; Neisser 1942) which created a hierarchy in compensation mechanisms of technological unemployment. In particular, the formation of new capital was considered

a condition sine qua non. That is, other mechanisms cannot work if the economy cannot supply enough capital to combine with the additional workforce. While German economists were aware of some critical aspects in assessing the efficacy of compensation theory, more conventional was the way in which the mechanism "via new investments" was revived by such marginalist economists as Alfred Marshall ([1890] 1961, 542) and Paul H. Douglas (1930, 936), and in more recent dynamic models by John R. Hicks (1973; also Hagemann and Hamouda 1994) and Paul Stoneman (1983a, 177-81; and 1983b).

4. The compensation mechanism "via decrease in wages": As with other forms of unemployment, the direct effect of labor-saving technologies may be compensated through a proper price adjustment in the labor market. In a neoclassical framework, with free competition and full substitutability between labor and capital, a decrease in wages would lead to an increase in the demand for labor. The first to apply this kind of argument to technological unemployment was Knut Wicksell ([1901–1906] 1961, 137), followed by John R. Hicks (1932, 56), Arthur C. Pigou (1933, 256), and Lionel C. Robbins (1934, 186). In modern times, wage adjustment is a component of partial equilibrium models, such as those by J. Peter Neary (1981) and Peter Sinclair (1981), and of general equilibrium analyses, such as those by Richard Layard and Stephen Nickell (1985), Anthony J. Venables (1985), and Richard Layard, Stephen Nickell and Richard Jackman (1991, 1994).

5. The compensation mechanism "via increase in incomes": Unlike the previous, this compensation mechanism has been put forward by the Keynesian and Kaldorian traditions. In a Fordist mode of production, unions take part in the distribution of the fruits of technical progress. So, one has to take into account that a portion of the cost savings due to technical change can emerge as an increased income and higher consumption. This increase in demand leads to a rise in employment which may fully compensate for the initial job losses due to process innovations (Boyer, 1988a, 1988b, and 1990; Pasinetti 1981).

6. The compensation mechanism "via new products": Despite the conventional approach identifying innovation with a movement of the production function of a given good, technological change is not only process innovation. It can also assume the form of creation and commercialization of new products, in which case, new economic branches develop and additional jobs emerge. Alongside classical economists (Say [1803] 1964, 88), pointing to the labor-intensive impact of product innovations, even the fiercest critic of compensation theory admitted that positive employment benefits can derive from this kind of technical progress:

> Entirely new branches of production, creating new fields of labour, are also formed, as the direct result either of machinery or of the general industrial changes brought about by it. (Marx [1867] 1961, 445)

In the current debate, various studies (Edquist, Hommen and McKelvey 2001; Freeman, Clark and Soete 1982; Freeman and Soete 1987, 1994; Vivarelli and Pianta 2000) agree that product innovations have a positive impact on employment since they open the way to developing either entirely new goods or new variants of existing goods. In the latter case, the "welfare effect" (new branches of production) has to be compared with the "substitution effect" (displacement of mature products) (Katsoulacos 1984, 1986).

On the whole, economic theory identifies those market forces which can potentially counterbalance the initial labor-saving impact of process innovation. Moreover, it is recognized that the alternative form of technological change — namely, the diffusion of entirely new products — can have a job-creating effect.

On the other hand, compensation mechanisms can be hindered, or even cancelled out, by the existence of some serious defects. Using the taxonomy proposed above, I will classify the main criticisms of compensation theory as follows:

First, with a few exceptions (see Hicks 1973), the compensation mechanism "via new machinery" has not received much attention lately. Indeed, Karl Marx's critique of it was so severe that it virtually wiped out the initial line of reasoning in compensation theory. As he argued, "the machine can only be employed profitably, if it … is the (annual) product of far fewer men than it replaces" (Marx [1905–1910] 1969, 552). Furthermore, labor-saving technologies spread around in the capital goods sector and substantially weaken the power of compensation mechanisms (Marx [1905–1910] 1969, 551). Finally, new machines can be put into effect either through additional investments (the third point below) or simply by substituting the obsolete ones (scrapping them). In the latter case, which is the most frequent one, there is no compensation taking place (Freeman, Clark and Soete 1982).

Second, as Thomas R. Malthus ([1836] 1964, 551-560) and Jean Charles Léonard Sismondi ([1819] 1971, 284) originally observed, the very first effect of labor-saving process innovations is a decrease in the aggregate demand due to workers' dismissal. So, the mechanism "via decrease in prices" deals with a decreased demand and has to counterbalance the initial reduction of the aggregate purchasing power. As James S. Mill ([1848] 1976, 97) put it, "the increased demand for commodities by some consumers will be balanced by a cessation of demand on the part of others, namely, the labourers who were superseded by the improvement." In addition, this mechanism relies on Say's law and does not take into account that demand constraints might occur. Difficulties concerning the "effective demand" components, such as low value of the "marginal efficiency of capital" (Keynes ([1936] 1973, ch. 11), may involve a delay in expenditure decisions and a lower demand elasticity.

It is important to note that postponing expenditures does not simply imply a lag in compensation. It can actually involve permanent technological unemployment for two basic reasons. On one side, if one takes the investment component of effective demand, "hoarding" assumes the form of speculative buying of financial assets, the motive of which is to get profit from selling the assets in the short term, rather than to save them for investing in fixed assets in the long term.[1] On the other side, even if one

[1] In Paul Davidson's (2002) terms, the degree of substitutability between tangible investments (i.e., capital formation) and intangible ones (i.e., money and financial assets) is very low. Acquiring new capital goods or storing wealth are two investment behaviors that imply quite different non-ergodic impacts in terms of effective demand and employment.

unrealistically assumes that the entire purchasing power is just transferred forward (so neglecting the first reason), technological change — a continuous and path-dependent process (Dosi 1988; Dosi and Nelson 2013; Freeman and Soete 1994) — would mean the introduction of further process innovation. This innovation would cause job losses that can be compensated only after a certain time lag, thus resulting in a permanent technological unemployment.[2] If such is the case, compensation mechanisms get hindered and technological unemployment ceases to be only a temporary problem (for a detailed criticism of compensation based on Say's law, see Standing 1984, 131-133). Finally, the effectiveness of the mechanism "via decrease in prices" depends on the hypothesis of perfect competition. If an oligopolistic regime is dominant, the whole compensation process will be seriously weakened since cost savings do not necessarily result in decreasing prices (Sylos-Labini [1956] 1969, 160).

Third, the compensation mechanism "via new investments" relies on the Say's law assumption that profits accumulated due to technical change are entirely and immediately channeled into additional investments. Theoretical analysis must take into account the Keynesian "animal spirits" and economic agents' expectations, which can delay the translation of additional profits into "effective demand" (Appelbaum and Schettkat 1995; Freeman and Soete 1987; Pasinetti 1981; Pianta 2005; Vivarelli 1995). Moreover, the intrinsic nature of new investments does matter. If these are capital-intensive, compensation can only be partial. As Marx ([1867] 1961, 628) wrote,"[t]he accumulation of capital, though originally appearing as its quantitative extension only, is effected, as we have seen, under a progressive qualitative change in its composition, under a constant increase of its constant, at the expense of its variable constituent."

Fourth, the mechanism "via decrease in wages" collides with the Keynesian theory of effective demand. On one hand, a decrease in wages can induce firms to hire additional workers. On the other hand, decreased aggregate demand lowers employers' expectations, and they would hire fewer workers. A second criticism can be leveled against this mechanism if the cumulative and irreversible nature of modern technical change is properly taken into account (Dosi 1988; Rosenberg 1976). In this view, science and technology have their own rules. When "localized technical progress" occurs along a "technological trajectory," this can give rise to "locked in" technologies (Freeman and Soete 1987, 42; Stiglitz 1987, 128). If the cumulative and localized nature of technical change is taken into account, the hypothesis of perfect substitutability between capital and labor assumed by neoclassical models appears to be quite arbitrary. At the same time, "there is inherent plausibility in the Hicks inducement theory, biasing the long term direction of technical change in a labour-saving direction. Attempts to generate a reversal of this trend by temporary small reductions in the relative price of labour are extremely unlikely to be effective" (Freeman and Soete 1987, 46; see also Vivarelli 2013, sec. 3).

Fifth, during the "golden age" of the 1950s and 1960s, the Fordist mode of production was based on a change in the nexus of labor and wage. Instead of letting wage be regulated by a competitive labor market, workers were allowed to take possession of a portion of the productivity gains resulting from technological progress. In turn, increased

[2] Both these arguments also substantiate the critique in the third point below.

real wages brought up mass consumption, and this stimulated investment leading to further productivity gains through technological progress and scale economies (Boyer 1988c, 1988d). Labor-saving technologies were introduced on a large scale, but the Kaldorian "virtuous circle" allowed an important compensation "via new incomes." The Fordist mode of production is now over for many reasons, which are outside the scope of this paper (Boyer 1988c, 1990). But the distribution of income now follows different rules and the labor market has returned to its competitive nature. On the whole, this compensation mechanism has been strongly weakened in the new institutional context.

Sixth, new products are still the more powerful way to counterbalance labor-saving process innovations. Yet, different "technological paradigms" (Dosi 1982) are characterized by different clusters of new products which, in turn, have very different impacts on employment. As a matter of fact, in different historical periods and various institutional frameworks, the relative balance between the labor-saving effect of process innovations and the labor-intensive impact of product innovations have varied considerably. For instance, the introduction of the automobile and other durables in the 1950s and 1960s had a much higher labor-intensive effect than the diffusion of home computers in the 1980s and 1990s. Indeed, on one hand, the mass production of cars was intensive in (unskilled) labor and opening up entire new sectors and patterns of demand. On the other hand, information and communication technologies (ICT) are intensive in (skilled) labor and they can be considered a product innovation for some capital sectors, such as microelectronics and telecommunications. At the same time, however, ICT represent (labor-saving) process innovation for user manufacturing sectors and for most of service sectors (Averitt 1968). The differential employment impacts of introducing new products, such as ICT-related ones, can be properly mapped through input-output analyses (see, for instance, Kalmbach and Kurz 1990; Leontief and Duchin 1986; Meyer-Krahmer 1992; Whitley and Wilson 1982).

Indeed, the relationship between innovation and employment is very complex, whereby the direct labor-saving impact of process innovation, compensation mechanisms, hindrances to the effectiveness of such mechanisms, and the labor-friendly nature of product innovation can combine in many diverse outcomes. However, economists sometimes forget that the relationship between technology and employment depends on historical and institutional circumstances.

In this respect, non-mainstream economic approaches open a well-balanced and articulated perspective. Specifically, the structural approach of Luigi Pasinetti and the long-run approach of Christopher Freeman and Carlota Perez deserve some attention.

In Pasinetti (1981), the dynamic process that affects modern capitalist economies can be properly described as a combination of different forces. When focusing on the relationship between technology and employment, technological progress involving an increase in average labor productivity should be contrasted to the diffusion of new products and the faster evolution in demand via price and income compensation mechanisms, as discussed above. What is important — and marks the difference between Pasinetti's and the mainstream approach — is that the final outcome of all these complex interactions does not assure full-employment either ex-ante or ex-post. As Pasinetti (1981, 90) observes:

> For the time being, we may draw the important conclusion that the structural dynamics of the economic system inevitably tend to generate what has rightly been called technological unemployment. At the same time, the very same structural dynamics produce counter-balancing movements which are capable of bringing macro-economic condition … towards fulfillment, but not automatically.

In particular, a proportional increase in demand coefficients, parallel to the increase in labor productivity, is rather unlikely since demand for mature products follows Engel's law, sooner or later converging to a level of saturation. Instead, Pasinetti is more confident in the introduction of new products[3] and/or in institutional changes, such as a decrease in the per-capita working time. In that respect, he (Pasinetti 1981, 231) states:

> The solution of these difficulties clearly cannot be that of preventing the introduction of the machines, as the "Luddite" workers thought in the nineteenth century. This would mean arresting the application of technical progress. … The correct answer to the problem is clearly that of introducing the machines, of producing with them the same physical quantities as before with fewer workers, and of employing the workers that have become redundant in the production of *other* commodities, old and new. Or, alternatively, to increase for all the proportion of leisure time to total time.

Interestingly enough, in mentioning the reduction of working time as a possible solution to technological unemployment, Pasinetti opens an institutional perspective that goes beyond the market mechanisms, counterbalancing, at least partially, the possible labor-saving effect of innovation. Indeed, John Maynard Keynes ([1930] 1972) was already aware that reduction of working time was a way to avoid what he explicitly called "technological unemployment." As a matter of fact, massive technological change and automation in the last two centuries has not produced mass unemployment, mainly because average yearly working time has halved from about 3,200 to about 1,600 hours per year (Maddison 1991; Sangheon, McCann and Messenger 2007).

In more general terms, the relationship between (and the debate on) technology and employment has been always heavily affected by institutional and historical contexts.[4] In this respect, neo-Schumpeterian scholars (Freeman, Clark and Soete 1982; Freeman and Soete 1987; Perez 1983) offer an interesting theoretical setting that bridges the short-

[3] More generally, Pasinetti's argument is that product innovation — in the form of new consumption goods — is a prerequisite for avoiding stagnation, and thus for fostering sustainable growth (Pasinetti 1981, 1993). This is in contrast to mainstream production theory that ignores product innovation and only focuses on technological change, seen as process innovation. Obviously, the diffusion of new consumption goods requires consumer learning (for a discussion, see Lundvall 2005).

[4] For instance, the Great Depression of the 1930s was a historical moment that facilitated a massive revival of the classical debate about technological unemployment among economists, policy-makers, and union officials (Woirol 1996).

terminism of economic analyses with a long-term perspective, or the long cycles. In the neo-Schumpeterian view, the Kondratiev new long waves originate from the diffusion of clusters of product innovations introduced and experimented with during the final phase of the former cycle. These innovations are basically expansionary, and substantially contribute to job creation. Then, when the long cycle reaches its maturity, the exhaustion of technological opportunities, generated by the dominant technological paradigm (Dosi 1982, 1988) and coupled with saturation effects on the demand side, involve downswing that manifests itself in harsh competition and cost-cutting technological change. In this context, process innovation becomes dominant.

In this view, institutional settings plays a crucial role both during economic boom and downturn in historical context. During a boom period, a good matching (see Perez 1983) between technological requirements and institutional setting (in terms of regulations, organizational change, economic policy, etc.) becomes a precondition for the new paradigm to manifest all its expansionary potentialities, including its job creation impact linked to the diffusion of new products. In a downturn period, institutions are a key factor in dealing with the negative consequences of recession. Thus, social safety nets, reduction of working time, and union strategies may be crucial in alleviating the consequences of technological unemployment due to the spread of process innovation. By the same token, compensation mechanisms can be more or less effective depending on the existing institutional setting. For instance, excessive regulation and lack of competition in the final market can hinder the mechanism "via decrease in prices," while capital market imperfections can hamper the mechanism "via new investments."

Although the institutional perspective deserves much more discussion than here allotted, this paper largely deals with economic mechanisms that operate in the short-to-medium term. In this respect, economic theory does not have a clear-cut answer regarding the employment effect of innovation. Attention should, therefore, focus on aggregate, sectoral, and microeconomic empirical analyses that take into account the different forms of technical change and their direct effects on labor, as well as the various compensation mechanisms and the possible hindrances they face.

Innovation and Employment: The Empirical Evidence

Whereas theoretical economists may develop clear models of the employment impact of process- and product innovation, applied economists have to "measure" process- and product innovation, compensation mechanisms, as well as the final employment effect of innovation. From this perspective, at least three main problems arise.

The first problem is that innovation is difficult to measure. Traditional indicators, such as R&D (input indicator), patents, and relevant innovation (output indicators), are seldom fully available and are often inadequate to fully represent technological progress. For instance, most of process innovation is implemented through "embodied technological change" (ETC),[5] introduced through gross investment. This technological

[5] The nature of technological progress and the effects related to its spread in an economy were originally discussed by William E.G. Salter (1960) and Robert M. Solow (1960) who underlined that

input is often more important than R&D activities. Consider, for instance, traditional sectors as well as small- and medium enterprises (SMEs), where in-house R&D has a very limited role and most innovation is introduced through the acquisition of capital goods. In terms of Keith Pavitt's (1984) taxonomy, technological change in "supplier dominated" firms is much more dependent on machinery acquired by specialized suppliers than on their own R&D expenditures. These circumstances are obviously quite crucial in DCs (see section, "A Focus on Developing Countries (DCs)" below).

In terms of job dynamics, the two faces of innovation — R&D and ETC — may imply different effects regarding employment, with R&D mainly correlated with labor-friendly product innovation and ETC with labor-saving process innovation. Indeed, using data from the European Community Innovation Surveys (CIS), recent microeconometric studies have empirically confirmed that R&D expenditures are closely linked to product innovation, while innovative investment (especially devoted to new machinery and equipment incorporating ETC) is related to process innovation (Conte and Vivarelli 2005; Parisi, Schiantarelli and Sembenelli 2006).

The second problem is that the final employment impact of innovation depends on institutional mechanisms that can be very different at the micro-, meso-, and macro-level. They can also vary in different economic contexts, such as in different countries or different sectors within the same country. For instance, a different degree of enforcement in intellectual property rights (IPRs) can induce a dissimilar balance in the distribution of R&D and ETC, and consequently will have different employment outcomes.[6]

The third problem relates to the difficulty of discerning the final impact of innovation on employment since the latter is influenced by many other factors: namely, macroeconomic and cyclical conditions, labor market dynamics, trends in working time, and others. Ultimately, macroeconomic empirical analyses of the relationship between innovation and employment are largely affected by these three methodological problems. On one hand, they are attractive because of their ability to account for all the direct and indirect effects of innovation (see previous section). On the other, they are often severely constrained by the difficulty to find a proper aggregate proxy of technological change, and by the fact that the final employment national trend is codetermined by overwhelming institutional and macroeconomic factors which are difficult to control for.

Albeit to a lesser extent, these considerations also apply when empirical analysis is carried out at the sectoral level. Moreover, sectoral analysis can be affected by either a negative or a positive bias, according to the observation point of view (e.g., manufacturing versus services). In this context, microeconometric studies have the advantage of allowing a direct and precise firm level mapping of innovation variables, both in terms of innovative inputs (R&D and ETC) and outputs (product and process innovation). Indeed, only firm-level data can account for R&D expenditures, capital formation,

technological progress might be incorporated in new vintages of capital, introduced either through additional investment or simply by scrapping. More recently, the role of capital accumulation in fostering productivity growth and economic development has been recognized by growth theorists (Abowd et al. 2007; Greenwood, Hercowitz and Krusell 1997; Hercowitz 1998; Hulten 1992; Wilson 2009).

[6] In DCs, weak IPR enforcement may induce under-investment in R&D and patentable activities.

product and process innovation, and can directly relate them to a firm's employment trend. In other words, only microeconometric empirical analysis can grasp the very nature of the innovative activities of firms and shed some light on how new products may generate new jobs, or how labor-saving process innovation may destroy existing ones.

The need for microeconometric analysis should also take into account important limitations of firm-level data. First, the microeconomic approach cannot fully account for the indirect compensation effects (see section two) which operate not only at the firm level, but also through intersectoral linkages and aggregate dynamics. Second, a possible shortcoming of this kind of analysis comes from a "positive bias" that tends to underline the positive employment consequences of innovation. In fact, once an empirical analysis is developed at the level of a single firm, innovative firms tend to have better employment performances since they gain market shares because of innovation. Even when innovation is labor-saving, microeconomic analyses generally show a positive link between technology and employment since they do not consider the important effect on rivals, which are crowded out by innovative firms (the so-called "business stealing" effect).

Keeping these methodological issues in mind, the next sections discuss the single level of empirical analysis on the relationship between technology and employment. The sections also briefly survey macroeconomic and sectoral studies, while providing a more detailed study of microeconometric literature.

Aggregate Empirical Evidence

As far as the aggregate empirical studies are concerned, macroeconometric studies attempt to test the validity of compensation mechanisms (see section two) within a partial or general equilibrium framework. For instance, Peter Sinclair (1981) put forward a macro IS/LM scheme and concluded that positive employment compensation can occur if the demand elasticity and the elasticity of factor substitution are sufficiently high. Using estimates based on U.S. data, Sinclair found strong evidence in support of the mechanism "via decrease in wages," but not of those "via decrease in prices."

Richard Layard and Stephen Nickell (1985) derived a demand for labor in a quasi-general equilibrium framework, and stated that the crucial parameter was the elasticity of the demand for labor in response to a variation in the ratio between real wages and labor productivity. In fact, technical change increases labor productivity and, given an adequate elasticity, the demand for labor as well, which can be enough to fully compensate initial job losses. Using data for the U.K. economy, Layard and Nickell estimated an elasticity coefficient equal to 0.9, which was sufficient, in their opinion, to rule out technical changes as a possible cause of rising British unemployment.[7]

Using a similar approach, Stephen Nickell and Paul Kong (1989) focused their attention on the operating of the compensation mechanism "via decrease in prices" in nine two-digit industries in the UK. Putting forward a price equation, where cost-saving effects of labor-saving technologies were fully transferred into decreasing prices, the

[7] See Vivarelli and Pianta (2000, ch. 1), for an extensive critical discussion on the role of technology and labor market flexibility in determining employment performance.

authors found that in seven sectors out of nine, sufficiently high-demand elasticity implied an overall positive impact of technical change on employment.

In a previous publication, I (Vivarelli 1995) have tentatively represented and estimated the direct labor-saving effect of process innovation, the compensation mechanisms, and the job-creating impact of product innovation based on a simultaneous equations model over the period 1960–1988. Running three stages least squares regressions, using Italian and U.S. data, I have shown that the more effective compensation mechanism is the one "via decrease in prices" in both countries, while other mechanisms are less important. In addition, the U.S. economy turned out to be more product-oriented (and so characterized by a positive relationship between technology and employment) than the Italian economy, in which different compensation mechanisms cannot counterbalance the labor-saving effect of prevailing process innovation.

Roberto Simonetti, Karl Taylor, and Marco Vivarelli (2000) apply the same simultaneous equations macroeconomic model, running three stages least squares regressions, using American, Italian, French, and Japanese data over the period 1965–1993. The authors show that the more effective compensation mechanisms are the ones "via decrease in prices" and "via increase in incomes" (especially in European countries until the mid-1980s). The other mechanisms are less significant and conditional on the institutional structures of the respective countries. For instance, the "mechanism via decrease in wages" is relevant in the flexible American labor market. Product innovation significantly reveals its labor-intensive potentiality only in the technological leader country in this period — the USA.

Sectoral Empirical Evidence

The sectoral dimension is particularly important in investigating the overall employment impact of innovation. In particular, the compensation mechanism "via new products" (which, in recent times, has often taken the form of a compensation "via new services") may accelerate the secular shift from manufacturing to services (Evangelista and Perani 1998; Evangelista and Savona 1998). On the other hand, new technologies in manufacturing seem to be characterized mainly by labor-saving ETC, only partially compensated by the market mechanisms discussed earlier. For instance, John Clark (1983, 1987) put forward a supply-oriented vintage model, investigating U.K. manufacturing. The author found that the *expansionary effect* of innovative investments (Keynesian multiplier) had been dominant until the mid-1960s, when the *rationalizing effect* (due to labor-saving ETC incorporated in investments and scrapping) started to overcome the expansionary one.

More recently, Mario Pianta, Rinaldo Evangelista, and Giulio Perani (1996) found an overall positive relationship between growth in value added and growth in employment. Nevertheless, especially in European countries, an important group of sectors displayed a markedly labor-saving trajectory (restructuring sectors), with growth in production and decline in employment.

In another study based on Italian data, Marco Vivarelli, Rinaldo Evangelista, and Mario Pianta (1996) showed that, in Italian manufacturing, the relationship between productivity growth and employment appeared to be negative. In particular, they revealed that product and process innovation had opposite effects on the demand for labor, in line with this paper's discussion.

As already mentioned, the scenario may change if service sectors are taken into account. For instance, using standardized sectoral data derived from national CISs, Mario Pianta (2000) and Tommaso Antonucci and Mario Pianta (2002) found an overall negative impact of innovation on employment in manufacturing industries across five European countries. By contrast, Rinaldo Evangelista (2000) and Rinaldo Evangelista and Maria Savona (2002) established a positive employment effect of technological change in the most innovative and knowledge-intensive service sectors.[8]

Looking into manufacturing and services jointly (using CIS cross-sectional sectoral data on relevant innovations for different European countries), Francesco Bogliacino and Mario Pianta (2010) found a positive employment impact of product innovation (which is particularly obvious in the high-tech manufacturing sectors, see Mastrostefano and Pianta 2009). Finally, running GMM-SYS panel estimations covering 25 manufacturing and service sectors for 15 European countries over the period 1996–2005, Bogliacino and Vivarelli (2012) found that R&D expenditures, mainly fostering product innovation, do show a job-creating effect.[9]

Microeconomic Empirical Evidence

While macroeconomic studies of the relationship between technology and employment seem to be confined to the 1980s and 1990s, literature devoted to the microeconometric investigation of the issue begun later. Nowadays, however, it is flourishing.

Being among the earlier contributors, Horst Entorf and Winfried Pohlmeier (1990) used a dummy variable to find a positive employment impact of product innovation in a cross-section of 2,276 West German firms in 1984. The positive employment impact of product innovation in West German manufacturing was confirmed by Werner Smolny (1998) using a panel of 2,405 firms for the period 1980 –1992.

Using the 1984 British Workplace Industrial Relations Survey, Stephen Machin and Sushil Wadhwani (1991) as well as David G. Blanchflower, Neil Millward and Andrew J. Oswald (1991) found out a negative raw correlation between ICT adoption and employment. Once controlled for workplace characteristics and fixed effects, however, the same correlation turned out to be positive.

In contrast to these authors, Erik Brouwer, Alfred Kleinknecht, and J.O.N. Reijnen (1993) discovered an aggregate negative relationship between aggregate R&D expenditures and employment (while the opposite emerged when only product

[8] It is a negative one in the case of financial-related sectors and most traditional services like trade and transport.

[9] As in the previous study, the labor-friendly impact of R&D expenditures turns out to be particularly significant in high-tech sectors.

innovation was considered) by using a cross-section of 859 Dutch manufacturing firms. Using microdata from sixteen German industries, Klaus Zimmermann (1991) similarly concluded that technological change was one of the determinants of rising unemployment in Germany during the 1980s.

Although the employment impact of innovation is not the main object of Mark Doms, Timothy Dunne, and Kenneth Trotske's (1997) study, they found that advanced manufacturing technologies, when measured by a set of dummy variables, were associated with higher employment growth in U.S. manufacturing plants over the period 1987–1991. More controversial results came from Tor J. Klette and Svein E. Førre (1998), whose database comprised 4,333 Norwegian manufacturing plants over the period 1982–1992. In contrast to most of other studies, they did not find any clear-cut positive relationship between net job creation and the R&D intensity of the examined plants.

Most recent studies have fully taken advantage of new available longitudinal datasets and applied more sophisticated panel data econometric methodologies. For example, John van Reenen (1997) matched the London Stock Exchange database of manufacturing firms with the SPRU innovation database and obtained a panel of 598 firms over the period 1976–1982. Running GMM-DIF estimates, he found a positive employment impact of innovation, and this result turned out to be robust after controlling for fixed effects, dynamics, and endogeneity.

By the same token, David G. Blanchflower and Simon M. Burgess (1998) confirmed a positive link between innovation (roughly measured with a dummy) and employment, using two different panels of British and Australian establishments. Their results showed to be robust after controlling for sectoral fixed effects, size of firm, and union density.

An interesting panel analysis was conducted by Nathalie Greenan and Dominique Guellec (2000), using microdata from 15,186 French manufacturing firms over the 1986–1990 period. According to this study, innovating firms — defined according to the outcomes of an innovation survey — create more jobs than non-innovating ones. However, the reverse is true at the sectoral level, where the overall effect is negative and only product innovation is job-creating. Interestingly, the opposite employment impact of innovation at the firm- and sectoral level may be due to the "business stealing effect" discussed above.

However, even when taking the "business stealing effect" into account,[10] Mariacristina Piva and Marco Vivarelli (2003, 2005) found evidence supporting a positive effect of innovation on employment at the firm level. Applying a GMM-SYS methodology to a longitudinal dataset of 575 Italian manufacturing firms over the period 1992–1997, the authors provided evidence of a significant, although small, positive link between firms' gross innovative investment and employment.

Using firm level data (obtained from the third wave of the Community Innovation Survey, CIS) from Germany, France, UK, and Spain, Rupert Harrison et al. (2008) put

[10] That is, controlling for lagged employment and current sales of firms.

forward a testable model, based on Bettina Peters (2004), which was able to distinguish the relative employment impact of process and product innovation (discrete variables). The authors concluded that process innovation tends to displace employment, while product innovation is labor friendly. However, compensation mechanisms are at work and, in the service sectors, are particularly effective when there is increased demand for new products. Bronwyn H. Hall, Francesca Lotti, and Jacques Mairesse (2008) applied a similar model to a panel of Italian manufacturing firms over the period 1995–2003 and found a positive employment contribution of product innovation. They found no evidence of unemployment resulting from process innovation.

More recently, Stefan Lachenmaier and Horst Rottmann (2011) presented a dynamic employment equation, including wages, gross value added, years and industries controls, and alternative proxies (dummies) of current and lagged product and process innovation. Based on a very comprehensive dataset of German manufacturing firms over the period 1982–2002, their GMM-SYS estimates showed a significantly positive impact of different innovation measures on employment. Partially in contrast to previous contributions, Lachenmaier and Rottmann observed a higher positive impact of process- rather than product innovation.[11]

Previous literature has rarely distributed the empirical analysis according to sectoral belonging. Among the few exceptions is Christine A. Greenhalgh, Mark Longland, and Derek Bosworth's (2001) contribution, which develops fixed effects estimates based on a panel of UK firms over the period 1987–1994. Consistent with most of the studies I discuss here, the authors found a positive, albeit modest, effect of R&D expenditures on employment. However, once Greenhalgh, Longland, and Bosworth analyzed the data according to sectoral belonging of firms, the positive impact of R&D on employment became limited to solely high-tech sectors. By contrast, when they divide the sectors into high- and low-tech, Lachenmaier and Rottmann (2011) did not find any significant sectoral heterogeneity in the effects of innovation on employment.

In a very recent study, Alex Coad and Rekha Rao (2011) limited their focus to high-tech U.S. manufacturing industries over the period 1963–2002. They investigated the impact of a composite innovativeness index (comprising information on both R&D and patents) on employment. The main outcome of their quantile regressions is that innovation and employment are positively linked and that innovation has a stronger impact on those firms showing the fastest employment growth. Finally, using a longitudinal database of 677 European manufacturing- and service firms over the period 1990–2008, Francesco Bogliacino, Mariacristina Piva, and Marco Vivarelli (2012) found that a positive and significant employment impact of R&D expenditures is detectable in services and high-tech manufacturing, but not in the more traditional manufacturing sectors.

[11] However, this result may be due to the discrete nature of the adopted measure of process and product innovation (dummy variables). Interestingly enough, once the authors restrict their attention to (important) product innovation, which went along with patent applications, they found a highly positive and significant employment effect.

On the whole, previous microeconometric evidence is not conclusive about the possible employment impact of innovation. Nevertheless, most recent panel investigations tend to support a positive link, especially when R&D and/or product innovation are adopted as proxies of technological change, and when high-tech sectors become the focus of study.

Innovation and Skills

Beyond the *quantitative* effect of new technologies on the number of employees, it is also important to investigate the *qualitative* effect of technological change on different categories of workers. The basic premise here is that innovations are skill-biased and, therefore, replace tasks traditionally carried out by unskilled workers with new jobs demanding skilled workers. Indeed, literature, focusing on the complementarity between technological change and skilled labor, has put forward the so-called "skill biased technological change" hypothesis (SBTC). Initially proposed by Zvi Griliches (1969) and Finis Welch (1970), this hypothesis supports the view that new technologies require suitable skills to be implemented effectively and efficiently.

A direct consequence of this hypothesis is that an insufficient number of qualified workers may be considered a constraint, which limits the adoption and diffusion of new technologies, on one hand, and the pursuit of full employment, on the other. This is the so called "human resource constraint" (Amendola and Gaffard 1988). In other words, in the presence of labor-saving and skill-biased process innovation, the scarcity of skilled labor can easily generate unemployment among unskilled workers, unless proper retraining policies are put in place.

However, literature on the skill-biased effect of technology is mainly empirical. It shows that, during the last three decades, while the new ICT technologies were rapidly spreading, the main OECD (Organization for Economic Cooperation and Development) countries have shown a significant change both in the composition of their labor force and wage shares in favor of skilled labor (Nickell and Bell 1995; OECD 1996, 1998).[12]

Depending on their institutional systems and the degree of flexibility of labor markets, economies have shown that either the "employment effect" or the "wage effect" have a dominant role. In particular, an increase in wage differentials between skilled and unskilled labor has been registered in both the United States (Autor, Katz and Krueger 1998) and the United Kingdom (Haskel and Slaughter 1998). At the same time, in continental European countries like France (Goux and Maurin 2000), Germany (Abraham and Houseman 1995), Italy (Casavola, Gavosto and Sestito 1996), and Sweden (Hansson 1997), the increase in wage differentials has been more

[12] Traditionally, workers are divided into two categories depending on the tasks they perform, skilled and unskilled. The first category includes workers who do not perform manual work (white collar), while the second includes workers doing physical jobs (blue collar). An alternative typology is based on education levels. The indicator based on tasks seems more suitable for verifying the presence of upskilling, deriving from labor demand. Meanwhile, the indicator based on education partly reflects the continuous increase in the supply of skills.

limited. Symmetrically, in the European countries, there has been a greater impact on employment figures, with higher unemployment levels partly due to the reduction of employment among unskilled workers.

From a methodological point of view, the empirical test of the SBTC hypothesis is generally based on the estimation of a restricted function of total variable costs, where capital and technology are assumed to be quasi-fixed factors. To implement Shephard's lemma, either the wage bill shares of each class of workers or the employment shares need to be derived and estimated using a proxy for technology.

What follows is a survey of the main empirical studies investigating the SBTC hypothesis. The analysis starts with articles regarding the U.S. economy and then shifts to literature concerning Canada, the UK, and continental Europe.

Eli Berman, John Bound, and Zvi Griliches's (1994) paper is considered the seminal publication that started the tradition of empirical testing of the SBTC hypothesis. In it, the authors analyzed the dynamics of 450 U.S. manufacturing sectors during the 1980s. Their econometric analysis related the employment shift in favor of skilled workers to the investments in computers and R&D. This result proved to be statistically significant in almost all sectors, thereby supporting the SBTC hypothesis. David H. Autor, Lawrence F. Katz, and Alan B. Krueger (1998) extended Berman, Bound, and Griliche's study over a longer period, 1950–1990, also including non-manufacturing sectors. Autor, Katz and Krueger confirmed the complementary relationship between investment in computers and the skill structure.

Sectoral outcomes concerning the U.S. economy have also been supported by studies using microdata. For instance, using U.S. manufacturing firms' data for the period 1972–1988, Dunne, Haltiwanger and Troske (1997) showed a positive, but not robust relation between seventeen advanced industrial technologies and skilled labor. However, they found a positive and significant relationship between R&D and skilled labor.

Doms, Dunne, and Troske (1997) followed a similar approach and showed that the use of advanced industrial technologies leads to a greater utilization of workers with higher qualifications in a cross-section analysis. This is the case even if the link between new technology and upskilling does not seem very significant once the time dimension (1987–1992) is taken into account. In other words, firms that introduce innovations have better-skilled workers both before and following the introduction.

In a later work, Catherine J. Morrison Paul and Donald S. Siegel (2001) tried to simultaneously assess the impact of trade, technology, and outsourcing on shifts in labor demand, using a dynamic cost function framework. On the basis of an iterative 3SLS method and data on U.S. manufacturing sectors (1959–1989) as well as computing cost elasticity measures for four educational classes of workers, these authors showed that technology has the strongest impact in favor of highly educated workers, while reducing the demand for workers without a college degree. They also found a strong interdependence between trade and computers, whereby trade-induced computerization compounds the negative effects on low skilled workers.

When studying the dynamics of the Canadian manufacturing economy between 1962 and 1986, using the SUR (Seemingly Unrelated Regression) method, Julian R.

Betts (1997) confirmed the fundamental role of the technological variable (measured just as a temporal trend). This variable not only causes replacement of the different productive inputs (WC, BC, energy, raw materials, and capital), but also generates a significant skill-biased effect in eleven out of eighteen sectors. In studying the dynamics of the Canadian manufacturing economy between 1981 and 1994, Surendra Gera, Wulong Gu, and Zhengxi Lin (2001) also highlighted the fundamental role of the technological variable (measured in four different dimension) in generating a significant skill-biased effect.

Empirical studies outside North America reveal results that are generally consistent with the SBTC hypothesis, albeit sometimes less strikingly. Using both firm- (1984–1990) and sector-level data (1979–1990) from the UK, Stephen Machin (1996) showed a positive relationship, on one hand, between the use of computers and skilled labor in the case of firms and, on another, between R&D intensity, number of innovations produced as well as used, and skilled labor in the sector analysis. Machin's results were reinforced by Jonathan E. Haskel and Ylva Heden's (1999) study at the firm level (covering the 1980s) which confirmed the positive relationship between investment in computers and increased skilled labor.

Regarding France, Jacque Mairesse, Nathalie Greenan, and Agnes Topiol-Bensaïd (2001) obtained results similar to those of Machin (1996). They used firm level data for 1986, 1990, and 1994, in a cross-section where the technological variables were ICT capital and ICT workers. However, only the negative relationship between ICT and less qualified labor was robust in time-series. Moreover, Dominique Goux and Eric Maurin (2000) showed how an increased spread of new technology (both computers and new industrial technology) explained only fifteen percent of the change in labor demand between 1970 and 1993 in their analysis of 34 French manufacturing sectors. Meanwhile, upskilling would be driven by internal demand towards skill-intensive productions.

For Germany, Martin Falk and Katja Seim (1999) studied the impact of new technologies on the more educated share of workers at the firm level (900 firms in 1994–1996) in service sectors. Firms devoting more resources in ICT employed more educated workers, even if the dimension of the relationship was small and strongly dependent on the specificity of sectors. But using a system of static and dynamic factor demand equations, and considering three categories of workers, Martin Falk (2001) showed how the increase in office machinery and computer capital accounted for at least sixty percent of expanding employment of university graduates in 35 manufacturing sectors for the period 1978–1994.

In Italy, Paola Casavola, Andrea Gavosto, and Paolo Sestito (1996) used the INPS database,[13] covering 36,000 Italian firms between 1986 and 1990, to study the effect of technological change on the labor demand and wages for skilled workers. They reached the conclusion that the wage difference between categories in Italy is lower than elsewhere, but that technological change had had a positive effect on the employment of skilled workers. However, on a sample of 412 manufacturing firms

[13] INPS stands for Italian National Institute for Social Security.

(1991–1997), Piva and Vivarelli (2001, 2002) found that the supposed link between R&D and skill bias did not seem to be confirmed. Otherwise, they showed that the reorganization process of production had a significant impact on workers. The organizational change at the work floor level especially seemed to drive the labor force's upskilling. This result does not mean that Italian manufacturing, heavily characterized by the presence of SMEs, is immune to SBTC. However, this probably does not take place mainly through internal channels — that is, in-house innovation resulting from R&D expenditure — but through organizational changes connected to the purchase and use of new technology. Mariacristina Piva, Enrico Santarelli, and Marco Vivarelli (2005) estimated a SUR model for a sample of Italian manufacturing firms, and confirmed that upskilling is more a function of reorganizational strategies than a consequence of technological change alone. Moreover, some evidence of super-additive effects emerges, which is consistent with the notion that technology and organization jointly affect the demand for labor. Analyses based on microdata, confined to a specific industry, provide more heterogeneous results. For instance, using an original firm-level panel dataset in the Italian machinery industry, Piva, Santarelli, and Vivarelli (2006) also showed that both skilled and unskilled workers can be negatively impacted by technological change. By the same token, Alberto Baccini and Martina Cioni (2010) recently focused on the impact of new technologies on the skill composition in the Italian textile industry, showing that ETC negatively affected low-skilled workers in most cases, while only in rare cases high-skilled occupations were displaced by new machinery.

In Spain, Victor Aguirregabiria and Cesar Alonso-Borrego (2001) used a panel of 1,080 manufacturing firms to test the relationship between new technologies and upskilling on the basis of a GMM estimator for dynamic panels. Taking as technological variable a dummy on the introduction of "technological capital," they confirmed the SBTC hypothesis, while detecting no significant effect for physical capital or R&D expenditure. Using an unbalanced panel data of approximately 1,000 Spanish firms in the 1990–1998 period, Adela Luque (2005) showed — through a decomposition methodology — that the rise in the skill-mix comes mainly from surviving firms' increasing their skill-mixes in response to re-tooling or upgrade in technology. Moreover, Luque (2005) found that firms belonging to high-tech sectors accounted for the majority of the skill-mix increase.

Some authors go beyond the national level. Stephen Machin and John van Reenen (1998) set up a panel at the manufacturing-sector level for seven countries: Denmark, France, Germany, Japan, Sweden, the UK, and the US. Their results showed that the relative demand for skilled workers was positively linked to R&D expenditure. The robustness of the results was confirmed both with reference to alternative econometric specifications and possible problems of endogeneity (i.e., the presence of an inverse causal relationship between technological innovation and skilled labor).[14] By and large, the body of evidence in favor of the skill-biased nature of

[14] The possible problem of endogeneity stems from the consideration that only firms, which already have skilled workers, see the potential for innovative investment. In the study under discussion, the

new technologies today is sizeable, robust, and relevant to different OECD countries, economic sectors, and innovation types.

A Focus on Developing Countries (DCs)

While most empirical literature on quantitative and qualitative employment impacts of technological change is centered on the OECD countries, attention has also been devoted to the specificities of middle- and low-income countries in recent times. What follows is an overview of literature that investigates this issue, beginning with the relationship between technology and employment, and then moving on to the diffusion of SBTC onto DCs.

Innovation and Employment in DCs

Technological change in DCs is mainly imported and innovation is inherently connected with trade, FDI, and consequent international technologic transfer (Acemoglu 2003; Keller 2004; Piva 2003). In fact, DCs (especially low-income ones) display a very limited capacity either in terms of in-house corporate R&D by the domestic firms, or in terms of public investment in R&D. Rather, new technologies are imported through licenses, and especially through the import of intermediate and capital goods from richer countries. This means that the dominant form of technological change within DCs is the ETC, contained in the capital goods (in primis machinery) which are imported from developed economies.

It is important to notice that these imported technologies are not necessarily the most updated in the world, but still are more advanced that those traditionally adopted by local firms in a DC. In other words, without necessarily assuming that advanced economies transfer their "best" technologies to DCs, it is quite reasonable to expect that transferred technologies are relatively more updated than those in use domestically.

In more detail, trade and FDI can imply a substantial technological upgrading in opening DCs through different channels. On one hand, a developing country can implement ETC through the import of "mature" machineries (including second-hand capital goods, see Barba Navaretti, Solaga and Takacs [1923] 1998) from more industrialized countries. On the other hand, a lagged DC can enjoy the "last-comer" benefit of jumping directly on a relatively new technology (Perkins and Neumayer 2005).[15] In addition to a direct effect through ETC, imports and FDI inflows may generate technological spillovers in favor of domestic firms which can absorb the new imported technologies through labor mobility, input-output relationships, and reverse

robustness control was successfully carried out by instrumenting the R&D expenditure technological variable with government expenditure in R&D — a variable that is not correlated with the error term (see also Piva and Vivarelli 2009).

[15] An example being the diffusion of mobile telecommunications in the countries of Sub-Saharan Africa, where traditional telephone networks are limited to a few urban areas.

engineering (Coe and Helpman 1995; Coe, Helpman and Homaister 1997). Finally, technological catch-up may be induced by exporting to richer countries, both through substituting/replacing outdated technologies in the exporting sectors, and through the development of entirely new businesses based on process- and product innovation intended to satisfy a more sophisticated demand of industrialized countries.

The paper will now turn to empirical literature that is investigating how import flows can contribute to international transfers of technology by providing DCs' local firms with access to new technologies. For instance, studying a sample of OECD countries, David T. Coe and Elhanan Helpman (1995) found that foreign knowledge embodied in traded goods has a statistically significant positive impact on aggregate total factor productivity (TFP) in importing countries. David T. Coe, Elhanan Helpman, and Alexander W. Homaister (1997) have extended the analysis to DCs and showed that imports of intermediate goods raise TFP in DCs as well. Just focusing on DCs, Jörg Mayer (2000) restricted the definition of import shares by considering only machinery, and found that the impact of foreign R&D in this case was much greater. Maurice Schiff and Yanling Wang (2006) underlined how trade-related technology diffusion can occur through an increase in a country's level of exposure to that technology through trade (quantity), or through improved knowledge of that trade (quality). Other studies have used firm-level database to examine imports as a mechanism for technological transfer and to find that imports can, in fact, improve firm technological capabilities (see, for example, Blalock and Veloso 2007).

With regard to export, breaking into foreign markets allows DC firms to acquire knowledge of international best practices. On one hand, foreign buyers often provide their suppliers with technical assistance and product design in order to improve the quality of imported goods. In addition, they may transmit to their suppliers, located in DCs, the knowledge tacitly acquired from other suppliers located in advanced countries (Epifani 2003). For instance, Stephen R. Yeaple (2005) showed that increased export opportunities make the adoption of new technologies profitable for more firms. Paula Bustos (2005) built a model based on the works of Yeaple (2005), while Marc Melitz (2003) argued that trade liberalization reduces variable export costs and makes adoption of new technologies more likely.

All in all, technology transfer in favor of DCs involves productivity gains that can be harmful to local DC's employment levels (on the link between innovation and productivity, see Mohnen and Hall 2013). In particular, the dominant role of imported ETC, implying labor-saving process innovation, can drastically decrease domestic demand for labor. As discussed by Lance Taylor (2004), the final employment outcome depends on the balance between labor productivity gains and output growth induced by domestic demand, trade, and FDI.[16] Therefore, in determining the final employment outcome, price and income compensation mechanisms are obviously crucial in DCs, too (Hall and Heffernan 1985).

[16] In his study, Taylor (2004) found that in seven out of eleven DCs, output per capita in traded goods sectors grew less rapidly than labor productivity, thereby implying job losses.

Different considerations can be put forward to support the view that "compensation" of labor-saving effects of new technologies may be more difficult in developing countries than in developed ones. First, as already mentioned, R&D-based product innovation is much more rare in DCs (and almost absent in low-income DCs), thus weakening the influence of this labor-friendly component of technological change on local employment. Second, price compensation mechanisms (via "decrease in prices" and via "decrease in wages," see above), can be severely hindered by low competition in local goods- and labor markets. Third, income compensation mechanisms (via "new investments" and via "new incomes") can be slowed down by a tendency to invest abroad and to spend extra incomes on imported luxury goods.

The ultimate effect in terms of growth and employment is mediated by the "absorptive capacity" of a given DC (Abramovitz 1986; Lall 2004). In other words, only those DCs which enjoy a sufficient level of endogenous R&D and innovation capabilities would be able to fully develop their new technology's growth and employment potentialities, with particular reference to labor-friendly product innovations. By the same token, public policy and government support may be crucial in fostering technological catch-up (such is the case of China, see Kim, Park and Lee 2013). However, most DCs may lack the institutional context that can be crucial in driving the job creation impact of product innovation, while alleviating its job-destructing potentialities. For instance, DCs often cannot offer a proper regulation environment, favoring the diffusion of new products (i.e., weaknesses in terms of patenting and IPRs in general). Similarly, rigidities and lack of competition in labor- and final goods markets may severely hinder the efficiency of price and income compensation mechanisms.

Skill-Biased Technological Change in DCs

From a theoretical point of view, trade liberalization (through the Heckscher-Ohlin theorem and its Stolper-Samuelson corollary, HOSS mechanism hereafter) and technological change could be responsible for the observed pattern of increased relative demand for skilled labor (see the relevant section above) in the developed world. By contrast, these two processes are supposed to have opposite effects in DCs (for an extensive analysis, see Lee and Vivarelli 2004, 2006a, and 2006b). On one hand, new technologies shift labor demand in favor of more skilled workers. On the other hand, the HOSS mechanism predicts that a DC, trading with "skill-abundant" developed economies, should specialize in the production of unskilled-labor-intensive goods and, therefore, should exhibit a relative increase in the demand for unskilled labor.

However, if the HOSS assumption of homogeneous production functions and identical technologies between countries is relaxed, then international openness may facilitate technology diffusion from industrialized to developing countries. This implies that trade and technological change are complementary, rather than alternative mechanisms. The idea is that trade liberalization will accelerate the flows of imported ETC (in machineries, intermediate inputs, and components) to DCs, while simultaneously inducing adaptation to skill-intensive technologies used in more advanced countries, and resulting in an increased demand for skilled workers (for a more extensive analysis, see Vivarelli 2004).

Donald Robbins (1996, 2003) and Donald Robbins and Tim H. Gindling (1999) called the effect of in-flowing technology, resulting from trade liberalization, the "skill-enhancing trade (SET) hypothesis." Their idea is that trade accelerates the flows of physical capital (and embodied technology) to the South, inducing rapid adaptation to skill-intensive technologies used in the North. The resulting increased demand for skilled labor may then lead to a widening wage and income dispersion in DCs.

There is a large body of empirical literature that has documented the SBTC hypothesis's relevance to advanced countries (see the relevant section above). At the same time, evidence for developing countries to that effect is less abundant. However, Eli Berman and Stephen Machin (2000, 2004) found that within-industry skill upgrading among middle-income countries was due to the adoption of the same kind of skill-biased technologies that had permeated industries in the developed world. This suggests that SBTC had been transferred rapidly from the developed world to middle-income countries, which emphasizes the SBTC's pervasive nature. Elena Meschi and Marco Vivarelli (2009) analyzed the impact of trade openness and technology transfer on income distribution in a panel of DCs. Once they disaggregated trade flows according to their areas of origin/destination, the authors found a significant inequality-enhancing effect in middle-income DCs due to trade with more advanced countries. This is possibly related to technological transfer and skill-enhancing trade. For a similar period, Rita K. Almeida (2009) reached identical conclusions using firm-level data for East Asia. Using a direct measure of embodied technological transfer, Andrea Conte and Marco Vivarelli (2011) likewise found that imported skill-biased technological change is one of the determinants of an increased relative demand for skilled workers in DCs.

While empirical cross-country literature supports the view that SBTC is rapidly diffusing into DCs (at least, into middle-income ones), the evidence from country-specific studies is mixed. On the basis of data on Mexican manufacturing plants, Gordon H. Hanson and Ann Harrison (1999) found that firms that receive FDI and acquire technology through licensing agreements or imported materials, also tend to hire more skilled workers. A similar conclusion was reached by Robert C. Feenstra and Gordon H. Hanson (1997), who used data on Mexican industries to find that FDI positively correlated with a relative demand for skilled labor. Pablo Fajnzylber and Ana Margarida Fernandes (2009) also found that increased levels of international integration linked to an increased demand for skilled labor in a cross-section of Brazilian firms.

By contrast, investigating the causes of skill upgrading in Chilean plants during the 1980s, Nina Pavcnik (2003) failed to find a significant relationship between measures of adopting foreign technology and the relative demand for skilled workers when she controlled for unobserved plant heterogeneity. However, Olga M. Fuentes and Simon Gilchrist (2005) extended her analysis over an additional nine-year time span (1979–1995) to find a robust association between the demand for skilled workers and the adoption of new foreign technologies.

Holger Görg and Erik Strobl (2002) analyzed a panel of manufacturing firms in Ghana over the 1990s. Their estimates revealed that, while the purchase of foreign machinery for technological purposes significantly raised the relative demand for skilled labor, a greater participation in world markets via exporting activities did not have any effect.

Bruno Giovanetti and Naercio Menezes-Filho (2006) analyzed the evolution of skilled employment in Brazil over the 1990–1998 period. First, they detected an increase in the skilled labor share. This increase was entirely due to the "within-industry" effect, while the "between-industries" effect was negative, in line with the HOSS predictions. Then, inspired by Machin and van Reenen (1998), they ran an econometric equation to test the SET hypothesis. Their variable was input tariffs, hypothesizing that the reduction of input tariffs should have induced import of technologically-advanced inputs, in turn, raising the demand for skilled labor. Consistently with their hypothesis, they found that tariffs related negatively to skill-upgrading, and that this effect was stronger in the sectors with inputs more complementary to skills.

Other papers have instead underlined the skill-enhancing effects of exporting activities, which makes the adoption of new technologies profitable for more firms (Yeaple 2005), induces quality upgrading (Fajnzylber and Fernandes 2009; Verhoogen 2008), and offers opportunities for acquiring knowledge of international best practice (for the so-called *learning-by-exporting* hypothesis, see Bigsten et al. 2004; Epifani 2003). In addition, domestic R&D and innovation, alongside imported technologies and exports, may play a relevant role at least for middle-income DCs (as in the case of advanced countries). For instance, Elena Meschi, Erol Taymaz, and Marco Vivarelli (2011) ran GMM-SYS estimates on panel data covering 17,462 Turkish manufacturing firms over the period 1980–2001. They showed that SET was an important factor in explaining the rise of skilled labor cost shares, together with domestic R&D. Using a panel database of Brazilian manufacturing firms over the period 1997–2005, Bruno Cesar Araújo, Francesco Bogliacino, and Marco Vivarelli (2011) also found evidence in support of both the role of SET and domestic technology in determining the skill-upgrading trend of Brazil's manufacturing labor force.

Conclusions

Whereas preliminary conclusions are discussed within the main body the paper, this section briefly summarizes the main findings. First, in terms of quantitative effects, process innovation tends to be labor-saving, while product innovation exhibits a labor-friendly nature. Second, according to the classical "compensation theory," market forces should assure a complete compensation of the initial labor-saving impact of process innovations. However, possible hindrances to compensation mechanisms may only allow partial compensation, depending on institutional settings and on the values of crucial parameters, such as demand elasticity, degree of competition, capital-labor substitution, demand expectations, and others. Third, since economic theory does not have a clear-cut answer about the employment effect of innovation, there is a strong need for aggregate, sectoral, and microeconomic empirical analyses, able to account for technological change, its direct effects on labor, compensation mechanisms, and possible hindrances to these mechanisms. Fourth, microeconometric studies have the great advantage of providing for direct and precise mapping of innovation variables on the firm level, both in terms of inputs and outputs. Indeed, only firm level data can account for R&D expenditures, capital formation, product and process innovation, and directly relate these variables to a firm's employment trends. Fifth, microeconometric literature in general, and the most recent panel data analyses in particular, tend to support a positive link between technology and employment, especially when R&D and/or product innovation are adopted as proxies of technological change as well as when high-tech sectors are taken into focus. Sixth, beyond the quantitative effect of new technologies on the number of employees, it is also important to investigate the qualitative effect of technological change for a possible skill bias. Nowadays, evidence in favor of the skill-biased nature of new technologies is large, robust, and applicable across OECD countries, economic sectors, and types of innovation.

Seventh, in developing countries, technological change is mainly imported and innovation is more determined by trade, FDI, and technology transfers, rather than by domestic private and public R&D expenditures. Eighth, in this respect, the paucity of R&D-based product innovation and the presence of institutional hindrances to compensation mechanisms make a net labor-saving impact of technology more likely in DCs than in developed countries. Ninth, as far as SBTC in DCs is concerned, a growing literature shows that there has been a rapid transfer of SBTC from the developed world to middle-income countries. This trend has not been so obvious in low-income DCs, which have a lower absorptive capacity. Tenth, recent empirical literature shows that both the SET and domestic technology are crucial factors in determining the observable skill-upgrading trend in middle-income DCs.

References

Abowd, John M., John Haltiwanger, Julia Lane, Kevin L. McKinney and Kristin Sandusky. "Technology and the Demand for Skill: An Analysis of Within and Between Firm Differences." IZA Discussion Paper No.2707. Bonn, Germany: IZA, 2007.

Abraham, Katharine and Susan Houseman. "Earnings Inequality in Germany." In *Differences and Changes in Wage Structures*, edited by Richard B. Freeman and Lawrence F. Katz, pp. 371-403. Chicago: University of Chicago Press, 1995.

Abramovitz, Moses. "Catching-up, Forging Ahead and Falling Behind." *Journal of Economic History* 46, 2 (1986): 385-406.

Acemoglu, Daron. "Patterns of Skill Premia." *Review of Economic Studies* 70, 2 (2003): 199-230.

Aguirregabiria, Victor and Cesar Alonso-Borrego. "Employment Occupational Structure, Technological Innovation, and Reorganization of Production." *Labour Economics* 8, 1 (2001): 43-73.

Almeida, Rita K. "Openness and Technological Innovation in East Asia: Have They Increased the Demand for Skills?" IZA Discussion Papers 4474. Bonn, Germany: IZA, 2009.

Amendola, Mario and Jean-Luc Gaffard. *The Innovative Choice*. Oxford: Basil Blackwell, 1988.

Antonucci, Tommaso and Mario Pianta. "Employment Effects of Product and Process Innovation in Europe." *International Review of Applied Economics* 16, 3 (2002): 295-307.
Appelbaum, Eileen and Ronald Schettkat. "Employment and Productivity in Industrialized Economies." *International Labour Review* 134, 4-5 (1995): 605-623.
Araújo, Bruno Cesar, Francesco Bogliacino and Marco Vivarelli. "Technology, Trade and Skills in Brazil: Some Evidence from Microdata." *CEPAL Review* 105 (2011): 157-171.
Autor, David H., Lawrence F. Katz and Alan B. Krueger. "Computing Inequality: Have Computers Changed the Labor Market?" *Quarterly Journal of Economics* 113, 4 (1998): 1169-1214.
Averitt, Robert T. *The Dual Economy: The Dynamics of American Industry Structure*. New York: Norton, 1968.
Baccini, Alberto and Martina Cioni. "Is Technological Change Really Skill-Biased? Evidence from the Introduction of ICT in the Italian Textile Industry (1980–2000)." *New Technology, Work and Employment* 25, 1 (2010): 80-93.
Barba Navaretti, Giorgio, Isidro Solaga and Wendy Takacs. "When Vintage Technology Makes Sense: Matching Imports to Skills." World Bank Working Paper. Washington, D.C.: [1923] 1998.
Berman, Eli and Stephen Machin. "Skill-Biased Technology Transfer Around the World." *Oxford Review of Economic Policy* 16, 1 (2000): 12-22.
——. "Globalization, Skill-Biased Technological Change and Labor Demand." In *Understanding Globalization, Employment and Poverty Reduction*, edited by Eddie Lee and Marco Vivarelli, pp. 39-66. New York: Palgrave Macmillan, 2004.
Berman, Eli, John Bound and Zvi Griliches. "Changes in the Demand for Skilled Labor Within U.S. Manufacturing Industries: Evidence from the Annual Survey of Manufacturing." *Quarterly Journal of Economics* 109, 2 (1994): 367-397.
Betts, Julian R. "The Skill Bias of Technological Change in Canadian Manufacturing Industries." *Review of Economics and Statistics* 79, 1 (1997): 146-150.
Bigsten, Arne, Paul Collier, Stefan Dercon, Marcel Fafchamps, Bernard Gauthier, Jan Willem Gunning, Abena Oduro, Remco Oostendorp, Cathy Pattillo, Mans Söderbom, Francis Teal and Albert Zeuf. "Do African Manufacturing Firms Learn from Exporting?" *Journal of Development Studies* 40, 1 (2004): 115-141.
Blalock, Garrick and Francisco M. Veloso. "Imports, Productivity Growth, and Supply Chain Learning." *World Development* 35, 7 (2007): 1134-1151.
Blanchflower, David G. and Simon M. Burgess. "New Technology and Jobs: Comparative Evidence from a Two-Country Study." *Economics of Innovation and New Technology* 5, 1 (1998): 109-138.
Blanchflower, David G., Neil Millward and Andrew J. Oswald. "Unionization and Employment Behavior." *Economic Journal* 101 (1991): 815-834.
Bogliacino, Francesco and Mario Pianta. "Innovation and Employment. A Reinvestigation Using Revised Pavitt Classes." *Research Policy* 39, 6 (2010): 799-809.
Bogliacino, Francesco, Mariacristina Piva and Marco Vivarelli. "R&D and Employment: An Application of the LSDVC Estimator Using European Data." *Economics Letters* 116, 1 (2012): 56-59.
Bogliacino, Francesco and Marco Vivarelli. "The Job Creation Effect of R&D Expenditures." *Australian Economic Papers* 51, 1 (2012): 96-113.
Boyer, Robert. "New Technologies and Employment in the 1980s: From Science and Technology to Macroeconomic Modelling." In *Barriers to Full Employment*, edited by Jan A. Kregel, Egon Matzner and Alessandro Roncaglia, pp. 233-268. London: Macmillan, 1988a.
——. "Assessing the Impact of R&D on Employment: Puzzle or Consensus?" Paper presented at the International Conference on New Technology: Its Impacts on Labour Markets and the Employment System, December 5-7, 1988b, Berlin, Germany.
——. "Technical Change and the Theory of Regulation." In *Technical Change and the Economic Theory*, edited by Giovanni Dosi, Christopher Freeman, Richard R. Nelson, Gerald Silverberg and Luc Soete, pp. 67-94. London: Pinter, 1988c.
——. "Formalizing Growth Regimes." In *Technical Change and the Economic Theory*, edited by Giovanni Dosi, Christopher Freeman, Richard R. Nelson, Gerald Silverberg and Luc Soete, pp. 608-635. London: Pinter, 1988d.
——. "The Capital Labor Relations in OECD Countries: From the Fordist "Golden Age" to Contrasted National Trajectories." Working paper CEPREMAP 9020. Paris, France: CEPREMAP, 1990.

Brouwer, Erik, Alfred Kleinknecht and J.O.N. Reijnen. "Employment Growth and Innovation at the Firm Level: An Empirical Study." *Journal of Evolutionary Economics* 3, 1 (1993): 153-159.

Bustos, Paula. "The Impact of Trade on Technology and Skill Upgrading: Evidence from Argentina." Mimeo, CREI and Universitat Pompeu Fabra. Barcelona, Spain: 2005.

Casavola, Paola, Andrea Gavosto and Paolo Sestito. "Technical Progress and Wage Dispersion in Italy: Evidence from Firms' Data." *Annales d'Economie et de Statistique* 41/42 (1996): 387-412.

Clark, John. *Essentials of Economic Theory*. New York: Macmillan, 1907.

——. "Employment Projections and Technological Change." In *The Employment Consequences of Technical Change*, edited by D.L. Bosworth, pp. 110-125. London: Macmillan, 1983.

——. "A Vintage-Capital Simulation Model." In *Technical Change and Full Employment*, edited by Christopher Freeman and Luc Soete, pp. 86-98. Oxford: Basil Blackwell, 1987.

Coad, Alex and Rekha Rao. "The Firm-Level Employment Effects of Innovations in High-Tech U.S. Manufacturing Industries." *Journal of Evolutionary Economics* 21, 2 (2011): 255-283.

Coe, David T. and Elhanan Helpman. "International R&D Spillovers." *European Economic Review* 39, 5 (1995): 859-887.

Coe, David T., Elhanan Helpman and Alexander W. Homaister. "North-South Spillovers." *Economic Journal* 107 (1997): 134-149.

Conte, Andrea and Marco Vivarelli. "One or Many Knowledge Production Functions? Mapping Innovative Activity Using Microdata." IZA Discussion Paper 1878. Bonn, Germany: IZA 2005.

——. "Imported Skill-Biased Technological Change in Developing Countries." *Developing Economies* 49, 1 (2011): 36-65.

Davidson, Paul. *Financial Markets, Money, and the Real World*. Northampton, MA: Edward Elgar, 2002.

Dobbs, Ian M., Martyn B. Hill and Michael Waterson. "Industrial Structure and the Employment Consequences of Technical Change." *Oxford Economic Papers* 39, 3 (1987): 552-567.

Doms, Mark, Timothy Dunne and Kenneth Troske. "Workers, Wages, and Technology." *Quarterly Journal of Economics* 112, 1 (1997): 253-289.

Dosi, Giovanni. "Technological Paradigms and Technological Trajectories." *Research Policy* 11, 1 (1982): 147-163.

——. "Source, Procedure and Microeconomic Effects of Innovation." *Journal of Economic Literature* 26, 3 (1988): 1120-1171.

Dosi, Giovanni and Richard R. Nelson. "The Evolution of Technologies: An Assessment of the State-of-the-Art." *Eurasian Business Review* 3, 1 (2013): 3-46.

Douglas, Paul H. "Technological Unemployment." *American Federationist* 37 (1930): 923-950.

Dunne, Timothy, John Haltiwanger and Kenneth Troske. "Technology and Jobs: Secular Changes and Cyclical Dynamics." *Carnegie-Rochester Conference Series on Public Policy* 46, 1 (1997): 107-178.

Edquist, Charles, Leif Hommen and Maureen McKelvey. *Innovation and Employment: Product Versus Process Innovation*. Cheltenham, UK: Edward Elgar, 2001.

Entorf, Horst and Winfried Pohlmeier. "Employment, Innovation and Export Activities." In *Microeconometrics: Surveys and Applications*, edited by Jean-Pierre Florens, Marc Ivaldi, Jean-Jacques Laffont and François Laisney, pp. 394-415. London: Basil Blackwell, 1990.

Epifani, Paolo. "Trade Liberalization, Firm Performance, and Labor Market Outcomes in the Developing World: What Can We Learn from Micro-Level Data?" World Bank Policy Research Working Paper Series 3063. Washington, D.C.: World Bank, 2003

Evangelista, Rinaldo. "Innovation and Employment in Services." In *The Employment Impact of Innovation: Evidence and Policy*, edited by Marco Vivarelli and Mario Pianta, pp. 121-148. London: Routledge, 2000.

Evangelista, Rinaldo and Giulio Perani. "Innovation and Employment in Services: Results from the Italian Innovation Survey." Paper presented at the EAEPE Conference, 5-8 November, 1998, Lisbon, Potugal.

Evangelista, Rinaldo and Maria Savona. "Patterns of Innovation in Services. The Results of the Italian Innovation Survey." Paper presented at the VIII Annual RESER Conference, October 8-10, 1998, Berlin.

——. "The Impact of Innovation on Employment in Services: Evidence from Italy." *International Review of Applied Economics* 16, 3 (2002): 309-318.

Fajnzylber, Pablo and Ana Margarida Fernandes. "International Economic Activities and Skilled Labor Demand: Evidence from Brazil and China." *Applied Economics* 41, 5 (2009): 563-577.

Falk, Martin. "The Impact of Office Machinery and Computer Capital on the Demand for Heterogeneous Labor." ZEW Discussion Paper 01-66. Mannheim, Germany: ZEW, 2001.

Falk, Martin and Katja Seim. "The Impact of Information Technology on High-Skilled Labor in Services: Evidence from Firm Level Panel Data." ZEW Discussion Paper 99-58. Mannheim, Germany: 1999.

Feenstra, Robert C. and Gordon H. Hanson. "Foreign Direct Investment and Relative Wages: Evidence from Mexico's Maquiladoras." *Journal of International Economics* 42, 3-4 (1997): 371-393.

Freeman, Christopher, John Clark and Luc Soete. *Unemployment and Technical Innovation*. London: Pinter, 1982.

Freeman, Christopher and Luc Soete, eds. *Technical Change and Full Employment*. Oxford: Basil Blackwell, 1987.

——. *Work for All or Mass Unemployment? Computerized Technical Change into the Twenty-First Century*. New York: Pinter, 1994.

Fuentes, Olga M. and Simon Gilchrist. "Trade Orientation and Labor Market Evolution: Evidence from Chilean Plant-Level Data." In *Labor Markets and Institutions*, edited by Jorge E. Restrepo and Andrea Tokman, pp. 411-435. Santiago: Central Bank of Chile, 2005.

Gera, Surendra, Wulong Gu and Zhengxi Lin. "Technology and the Demand for Skills: An Industry-Level Analysis." *Canadian Journal of Economics* 34, 1 (2001): 132-148.

Giovanetti, Bruno and Naercio Menezes-Filho. "Trade Liberalization and Demand for Skilled Labor in Brazil." *Economia (Journal of LACEA)* 7, 1 (2006): 1-28.

Görg, Holger and Erik Strobl. "Relative Wages, Openness and Skill-Biased Technological Change." IZA Discussion Papers 596. Bonn, Germany: IZA, 2002.

Goux, Dominique and Eric Maurin. "The Decline in Demand for Unskilled Labor: An Empirical Method and Its Application to France." *Review of Economics and Statistics* 82, 4 (2000): 596-607.

Greenan, Nathalie and Dominique Guellec. "Technological Innovation and Employment Reallocation." *Labour* 14, 4 (2000): 547-590.

Greenhalgh, Christine A., Mark Longland and Derek Bosworth. "Technological Activity and Employment in a Panel of U.K. Firms." *Scottish Journal of Political Economy* 48, 3 (2001): 260-282.

Greenwood, Jeremy, Zvi Hercowitz and Per Krusell. "Long-Run Implications of Investment-Specific Technological Change." *American Economic Review* 87, 3 (1997): 342-362.

Griliches, Zvi. "Capital-Skill Complementarity." *Review of Economics and Statistics* 51, 4 (1969): 465-468.

Hagemann, Harald and Omar Hamouda. *The Legacy of Sir John Hicks*. Abingdon, UK: Routledge, 1994.

Hall, Bronwyn H., Francesca Lotti and Jacques Mairesse. "Employment, Innovation, and Productivity: Evidence from Italian Microdata." *Industrial and Corporate Change* 17, 4 (2008): 813-839.

Hall, Philip H. and Shelagh A. Heffernan. "More on the Employment Effects of Innovation." *Journal of Development Economics* 17, 1-2 (1985): 151-162.

Hanson, Gordon H. and Ann Harrison. "Trade and Wage Inequality in Mexico." *Industrial and Labor Relations Review* 52, 2 (1999): 271-288.

Hansson, Par. "Trade, Technology and Changes in Employment of Skilled Labor in Swedish Manufacturing." In *Technology and International Trade*, edited by Jean Fagerberg, Par Hansson, Lars Lundberg and Arne Melchior, pp. 200-216. Aldershot, UK: Edward Elgar, 1997.

Harrison, Rupert, Jordi Jaumandreu, Jacques Mairesse and Bettina Peters. "Does Innovation Stimulate Employment? A Firm-Level Analysis Using Comparable Microdata from four European Countries." NBER Working Papers 14216. Cambridge MA: NBER, 2008.

Haskel, Jonathan E. and Ylva Heden. "Computers and the Demand for Skilled Labor: Industry and Establishment-Level Evidence for the UK." *Economic Journal* 109 (1999): C68-C79.

Haskel, Jonathan E. and Matthew Slaughter. "Does the Sector Bias of Skill Biased Technical Change Explain Changing Wage Inequality?" NBER Working Paper 6565. Cambridge, MA: NBER, 1998.

Heffernan, Shelagh A. *Technological Unemployment*. PhD diss., Oxford University, 1981.

Hercowitz, Zvi. "The 'Embodiment' Controversy: A Review Essay." *Journal of Monetary Economics* 41 (1998): 217-224.

Hicks, John R. *The Theory of Wages*. London: Macmillan, 1932.

——. *Capital and Time*. Oxford: Oxford University Press, 1973.

Hobsbawm, Eric J. *Industry and Empire: An Economic History of Britain Since 1750*. Harmondsworth, Middlesex, UK: Penguin Books, 1968.

Hobsbawm, Eric J. and George Rudé. *Captain Swing*. London: London Reader's Union, 1969.

Hulten, Charles R. "Growth Accounting When Technical Change Is Embodied in Capital." *American Economic Review* 82, 4 (1992): 964-980.

Kalmbach, Peter and Heinz D. Kurz. "Micro-Electronics and Employment: A Dynamic Input-Output Study of the West-German Economy." *Structural Change and Economic Dynamics* 1, 2 (1990): 371-386.

Katsoulacos, Yannis S. "Product Innovation and Employment." *European Economic Review* 26, 1 (1984): 83-108.

——. *The Employment Effect of Technical Change*. Brighton, UK: Wheatsheaf, 1986.

Keller, Wolfgang. "International Technology Diffusion." *Journal of Economic Literature* 42, 3 (2004): 752-782.

Keynes, John Maynard. "Economic Possibilities for Our Grandchildren." In *The Collected Writings of John Maynard Keynes*, volume nine, pp. 321-332. London: Macmillan, [1930] 1972.

——. *The General Theory of Employment, Interest and Money*. Volume seven. London: Macmillan, [1936] 1973.

Kim, Jun-Youn, Tae-Young Park and Keun Lee. "Catch-up by Indigenous Firms in the Software Industry and the Role of the Government in China: A Sectoral System of Innovation (SSI) Perspective." *Eurasian Business Review* 3, 1 (2013): 100-120.

Klette, Tor J. and Svein E. Førre. "Innovation and Job Creation in a Small Open Economy: Evidence from Norwegian Manufacturing Plants 1982–1992." *Economics of Innovation and New Technology* 5, 2 (1998): 247-272.

Lachenmaier, Stefan and Horst Rottmann. "Effects of Innovation on Employment: A Dynamic Panel Analysis." *International Journal of Industrial Organization* 29, 2 (2011): 210-220.

Lall, Sanjaya. "The Employment Impact of Globalization in Developing Countries." In *Understanding Globalization, Employment and Poverty Reduction* edited by Eddy Lee and Marco Vivarelli, pp. 73-101. New York: Palgrave Macmillan, 2004.

Layard, Richard and Stephen Nickell. "The Causes of British Unemployment." *National Institute Economic Review* 111, 1 (1985): 62-85.

Layard, Richard, Stephen Nickell and Richard Jackman. *Unemployment: Macroeconomic Performance and the Labor Market*. Oxford: Oxford University Press, 1991.

——. *The Unemployment Crisis*. Oxford: Oxford University Press, 1994.

Lederer, Emil. *Technischer Fortschritt und Arbeitslosigkeit*. Tubingen: J.C.B. Mohr, 1931.

Lee, Eddy and Marco Vivarelli, eds. *Understanding Globalization, Employment and Poverty Reduction*. New York: Palgrave Macmillan, 2004.

——. *Globalization, Employment and Income Distribution in Developing Countries*. New York: Palgrave Macmillan, 2006a.

——. "The Social Impact of Globalization in Developing Countries." *International Labour Review* 145, 1 (2006b): 167-184.

Leontief, Wassily and Faye Duchin. *The Future Impact of Automation on Workers*. Oxford: Oxford University Press, 1986.

Lowe, Adolph. *The Path of Economic Growth*. Cambridge: Cambridge University Press, 1976.

Lundvall, Bengt-Ake. "Interactive Learning, Social Capital and Economic Performance." Paper presented at the conference, "Advancing Knowledge and the Knowledge Economy," organized by EC, OECD, and NSF-US, January 10-11, 2005, Washington, D.C.

Luque, Adela. "Skill Mix and Technology in Spain: Evidence from Firm-Level Data." Banco de Espana, Documento de Trabajo 0513. Madrid, Spain: Banco de Espana, 2005.

Machin, Stephen. "Changes in the Relative Demand for Skills. In *Acquiring Skills: Market Failures, Their Symptoms and Policy Responses*, edited by Alison L. Booth and Dennis J. Snower, pp. 129-146. Cambridge: Cambridge University Press, 1996.

Machin, Stephen and John van Reenen. "Technology and Changes in Skill Structure: Evidence from Seven OECD Countries." *Quarterly Journal of Economics* 113, 4 (1998): 1215-1244.

Machin, Stephen and Sushil Wadhwani. "The Effects of Unions on Organizational Change and Employment: Evidence from WIRS." *Economic Journal* 101 (1991): 324-330.

Maddison, Angus. *Dynamic Forces in Capitalist Development: A Long-Run Comparative View*. Oxford: Oxford University Press, 1991.

Mairesse, Jacque, Nathalie Greenan and Agnes Topiol-Bensaïd. "Information Technology and Research and Development Impacts on Productivity and Skills: A Comparison on French Firm Level Data." NBER Working Paper 8075. Cambridge, MA: NBER, 2001.

Malthus, Thomas R. *Principles of Political Economy*. New York: M. Kelley, [1836] 1964.

Marshall, Alfred. *Principles of Economics*. Cambridge: Macmillan, [1890] 1961.

Marx, Karl. *Capital*. Moscow: Foreign Languages Publishing House, [1867] 1961.

——. *Theories of Surplus Value*. London: Lawrence & Wishart, [1905–1910] 1969.

Mastrostefano, Valeria and Mario Pianta. "Technology and Jobs." *Economics of Innovation and New Technology* 18, 8 (2009): 729-741.

Mayer, Jörg. "Globalization, Technology Transfer and Skill Accumulation in Developing Countries." UNCTAD Discussion Paper 150, Geneva, Switzerland: UNCTAD, 2000.

Melitz, Marc. "The Impact of Trade on Aggregate Industry Productivity and Intra-Industry Reallocations." *Econometrica* 71, 6 (2003): 1695-1725.

Meschi, Elena and Marco Vivarelli. "Trade and Income Inequality in Developing Countries." *World Development* 37, 2 (2009): 287-302.

Meschi, Elena, Erol Taymaz and Marco Vivarelli. "Trade, Technology and Skills: Evidence from Turkish Microdata." *Labour Economics* 18, 1 (2011): S60-S70.

Meyer-Krahmer, Frieder. "The Effects of New Technologies on Employment." *Economics of Innovation and New Technology* 2, 1 (1992): 131-149.

Mill, James S. *Principles of Political Economy*. New York: M. Kelley, [1848] 1976.

Mohnen, Pierre and Bronwyn H. Hall. "Innovation and Productivity: An Update." *Eurasian Business Review* 3, 1 (2013): 47-65.

Morrison Paul, Catherine J. and Donald S. Siegel. "The Impacts of Technology, Trade and Outsourcing on Employment and Labor Composition." *Scandinavian Journal of Economics* 103, 2 (2001): 241-264.

Neary, J. Peter. "On the Short-Run Effects of Technological Progress." *Oxford Economic Papers* 32, 3 (1981): 224-233.

Neisser, Hans P. "Permanent" Technological Unemployment." *American Economic Review* 32, 1 (1942): 50-71.

Nickell, Stephen and Brian Bell. "The Collapse in Demand for the Unskilled and Unemployment Across the OECD." *Oxford Review of Economic Policy* 11, 1 (1995): 40-62.

Nickell, Stephen and Paul Kong. "Technical Progress and Jobs." London School of Economics, Centre for Labour Economics, Discussion Paper 366. London: London School of Economics, 1989.

OECD. "The Evolution of Skills in OECD Countries and the Role of Technology." STI Working Paper 1996/8. Paris, France: OECD, 1996.

——. "OECD Data on Skills: Employment by Industry and Occupation." STI Working Paper 1998/4. Paris, France: OECD, 1998.

Parisi, Maria Laura, Fabio Schiantarelli and Alessandro Sembenelli. "Productivity, Innovation and R&D: Micro Evidence for Italy." *European Economic Review* 50, 8 (2006): 2037-2061.

Pasinetti, Luigi. *Structural Change and Economic Growth*. Cambridge: Cambridge University Press, 1981.

——. *Structural Economic Dynamics: A Theory of the Economic Consequences of Human Learning*. Cambridge: Cambridge University Press, 1993.

Pavcnik, Nina. "What Explains Skill Upgrading in Less Developed Countries?" *Journal of Development Economics* 71, 2 (2003): 311-328.

Pavitt, Keith. "Patterns of Technical Change: Towards a Taxonomy and a Theory." *Research Policy* 13, 6 (1984): 343-374.

Perez, Carlota. "Structural Change and the Assimilation of New Technologies in the Economic and Social System." *Futures* 15, 4 (1983): 357-375.

Perkins, Richard and Eric Neumayer. "International Technological Diffusion, Latecomer Advantage and Economic Globalization: A Multi-technology Analysis." *Annals of the American Association of Geographers* 95, 4 (2005): 789-808.

Peters, Bettina. "Employment Effects of Different Innovation Activities: Microeconometric Evidence." ZEW Discussion Papers 0473. Bonn, Germany: ZEW, 2004.

Petit, Pascal. "Employment and Technological Change." In *Handbook of the Economics of Innovation and Technological Change*, edited by Paul Stoneman, pp. 366-408. Amsterdam, The Netherlands: North Holland, 1995.

Pianta, Mario. "The Employment Impact of Product and Process Innovations." In *The Employment Impact of Innovation: Evidence and Policy* edited by Marco Vivarelli and Mario Pianta, pp. 77-95. London: Routledge, 2000.

——. "Innovation and Employment." In *Handbook of Innovation*, edited by Jan Fagerberg, David C. Mowery and Richard R. Nelson, pp. 568-598. Oxford: Oxford University Press, 2005.

Pianta, Mario, Rinaldo Evangelista and Giulio Perani. "The Dynamics of Innovation and Employment: An International Comparison." *STI Review* 18 (1996): 67-93.

Pigou, Arthur C. *The Theory of Unemployment*. London: Macmillan, 1933.

——. *The Economics of Welfare*. London: Macmillan, [1920] 1962.

Piva, Mariacristina. "The Impact of Technology Transfer on Employment and Income Distribution in Developing Countries: A Survey of Theoretical Models and Empirical Studies." International Labor Office (ILO), International Policy Group Working Paper 15. Geneva, Switzerland: ILO, 2003.

Piva, Mariacristina and Marco Vivarelli. "The Skill Bias in Italy: A First Report." *Economics Bulletin* 15, 1 (2001): 1-8.

——. "The Skill Bias: Comparative Evidence and an Econometric Test." *International Review of Applied Economics* 16, 3 (2002): 347-357.

——. "Technological Change and Employment: Some Micro Evidence from Italy." *Applied Economics Letters* 11, 6 (2004): 373-376.

——. "Innovation and Employment: Evidence from Italian Microdata." *Journal of Economics* 86, 1 (2005): 65 -83.

——. "The Role of Skills as a Major Driver of Corporate R&D." *International Journal of Manpower* 30, 8 (2009): 835-852.

Piva, Mariacristina, Enrico Santarelli and Marco Vivarelli. "The Skill Bias Effect of Technological and Organizational Change: Evidence and Policy Implications." *Research Policy* 34, 1 (2005): 141-157.

——. "Technological and Organizational Changes as Determinants of the Skill Bias: Evidence from the Italian Machinery Industry." *Managerial and Decision Economics* 27, 1 (2006): 63-73.

Ricardo, David. *The Works and Correspondence of David Ricardo: Principles of Political Economy and Taxation, Volume 1.* Edited by Piero Sraffa. Cambridge: Cambridge University Press, [1821] 1951.

Robbins, Donald. "HOS Hits Facts: Facts Win; Evidence on Trade and Wages in the Developing World." OECD Technical Paper 119. Paris, France: OECD, 1996.

——. "The Impact of Trade Liberalization upon Inequality in Developing Countries – A Review of Theory and Evidence." International Labor Organization (ILO) Working Paper 13. Geneva, Switzerland: ILO, 2003.

Robbins, Lionel C. *The Great Depression*. London: Macmillan, 1934.

Robbins, Donald and Tim H. Gindling. "Trade Liberalization and the Relative Wages for More-Skilled Workers in Costa Rica." *Review of Development Economics* 3, 1 (1999): 140-154.

Rosenberg, Nathan. *Perspectives on Technology*. Cambridge: Cambridge University Press, 1976.

Salter, William E.G. *Productivity and Technical Change*. Cambridge: Cambridge University Press, 1960.

Sangheon Lee, Deirdre McCann and Jon C. Messenger. *Working Time Around the World*. Abingdon, UK: Routledge, 2007.

Say, Jean-Baptiste. *A Treatise on Political Economy or the Production, Distribution and Consumption of Wealth*. New York: M. Kelley, [1803] 1964.

Schiff, Maurice and Yanling Wang. "On the Quantity and Quality of Knowledge: The Impact of Openness and Foreign R&D on North-North and North-South Technology Spillovers." In *Global Integration and Technology Transfer*, edited by Bernard Hoeckman and Beata S. Javoricik, pp. 99-112. New York: Palgrave Macmillan and World Bank, 2006.

Simonetti, Roberto, Taylor, Karl and Marco Vivarelli. "Modeling the Employment Impact of Innovation." In *The Employment Impact of Innovation: Evidence and Policy*, edited by Marco Vivarelli and Mario Pianta, pp. 26-43. London: Routledge, 2000.

Sinclair, Peter. "When Will Technical Progress Destroy Jobs?" *Oxford Economic Papers* 31, 1 (1981): 1-18.

Sismondi, Jean Charles Léonard. *Nouveaux Principes d'Economie Politique ou de la Richesse dans ses Rapports avec la Population*. Paris, France: Calmann-Levy, [1819] 1971.

Smolny, Werner. "Innovations, Prices and Employment: A Theoretical Model and an Empirical Application for West German Manufacturing Firms." *Journal of Industrial Economics* 46, 3 (1998): 359 -381.

Solow, Robert M. "Investment and Technical Progress." In *Mathematical Methods in the Social Sciences*, edited by Kenneth J. Arrow, Samuel Karlin and Patrick Suppes, pp. 89-104. Stanford: Stanford University Press, 1960.

Standing, Guy. "The Notion of Technological Unemployment." *International Labour Review* 123, 1 (1984): 127-147.

Steuart, James. *An Inquiry into the Principles of Political Economy*. Chicago: Oliver and Boyd, [1767] 1966.

Stiglitz, Joseph E. "Learning to Learn, Localized Learning and Technological Progress." In *Technology Policy and Economic Performance* edited by Partha Dasgupta and Paul Stoneman, pp. 125-153. Cambridge: Cambridge University Press, 1987.

Stoneman, Paul. *The Economic Analysis of Technological Change*. Oxford: Oxford University Press, 1983a.

——. "New Technology, Demand and Employment." In *The Employment Consequences of Technological Change*, edited by Derek L. Bosworth, pp. 82-96. London: Macmillan, 82-96, 1983b.

Sylos-Labini, Paolo. *Oligopoly and Technical Progress*. Cambridge M.A.: Harvard University Press, [1956] 1969.

Taylor, Lance. "External Liberalization in Asia, Post-Socialist Europe and Brazil." In *Understanding Globalization, Employment and Poverty Reduction*, edited by Eddy Lee and Marco Vivarelli, pp. 13-34. New York: Palgrave Macmillan, 2004.

Van Reenen, John. "Employment and Technological Innovation: Evidence from U.K. Manufacturing Firms." *Journal of Labor Economics* 15, 2 (1997): 255-284.

Venables, Anthony J. "The Economic Implications of a Discrete Technical Change." *Oxford Economic Papers* 37, 2 (1985): 230-248.

Verhoogen, Eric A. "Trade, Quality Upgrading, and Wage Inequality in the Mexican Manufacturing Sector." *Quarterly Journal of Economics* 123, 2 (2008): 489-530.

Vivarelli, Marco. *The Economics of Technology and Employment: Theory and Empirical Evidence*. Aldershot, UK: Edward Elgar, 1995.

——. "Globalization, Skills and Within-Country Income Inequality in Developing Countries." In *Understanding Globalization, Employment and Poverty Reduction*, edited by Eddy Lee and Marco Vivarelli, pp. 211-243. New York: Palgrave Macmillan, 2004.

——. "Technology, Employment and Skills: An Interpretative Framework." *Eurasian Business Review* 3, 1 (2013): 66-89.

Vivarelli, Marco and Mario Pianta. *The Employment Impact of Innovation: Evidence and Policy*. London: Routledge, 2000.

Vivarelli, Marco, Rinaldo Evangelista and Mario Pianta. "Innovation and Employment in Italian Manufacturing Industry." *Research Policy* 25, 7 (1996): 1013-1026.

Welch, Finis. "Education in Production." *Journal of Political Economy* 78, 1 (1970): 35-59.

Whitley, John D. and Robert A. Wilson. "Quantifying the Employment Effects of Micro-Electronics." *Futures* 14, 6 (1982): 486-495.

Wicksell, Knut. *Lectures on Political Economy*. London: Routledge & Kegan, [1901–1906] 1961.

Wilson, Daniel J. "IT and Beyond: The Contribution of Heterogeneous Capital to Productivity." *Journal of Business and Economic Statistics* 27, 1 (2009): 52-70.

Woirol, Gregory R. *The Technological Unemployment and Structural Unemployment Debates*. Westport: Greenwood Press, 1996.

Yeaple, Stephen R. "A Simple Model of Firm Heterogeneity, International Trade and Wages." *Journal of International Economics* 65, 1 (2005): 1-20.

Zimmermann, Klaus. "The Employment Consequences of Technological Advance: Demand and Labor Costs in 16 German Industries." *Empirical Economics* 16, 2 (1991): 253-266.