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I Z A
World of Labor
Evidence-based policy making

Innovation and employment

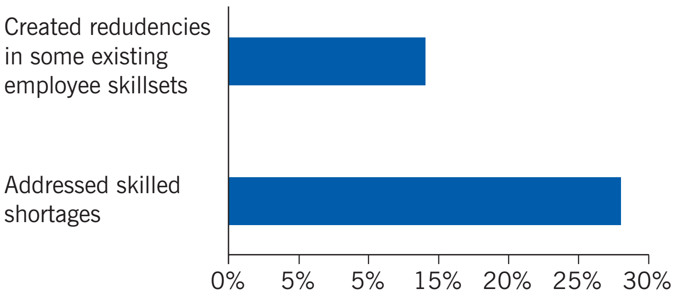
Technological unemployment is not inevitable—some innovation creates jobs, and some job destruction can be avoided

Keywords: innovation, technological change, R&D, employment, technological unemployment

ELEVATOR PITCH

Studies find that technological change has contributed to the decline in manufacturing and to persistent unemployment in many advanced economies. While process innovation can be job-destroying, product innovation can imply the emergence of new firms, new sectors, and thus new jobs. But even for process innovation, the final impact on labor demand is shaped by market mechanisms that can compensate for the direct job-destroying impact if market and institutional rigidities do not impede them. Policies should maximize the job-creation effect of product innovation and minimize the direct labor-saving impact of process innovation.

What has technology done for you lately (the Americas, 2014)?



Source: EY Global Job Creation Survey 2014. Online at: http://www.ey.com/Publication/vwLUAssets/EY_-_Global_job_creation_survey_June_2014/$FILE/Global-job-creation-survey-june-2014.pdf

KEY FINDINGS

Pros

- R&D fosters labor-friendly product innovation that leads to job creation.
- Product innovation may imply the emergence of new firms and new sectors and thus new jobs.
- Price and income compensation mechanisms can counterbalance the initial displacement of workers that occurs following process innovation.
- Empirical evidence reveals the possible job-creation impact of innovation.
- Industrial and innovation policies that support R&D and product innovation, especially in high-tech sectors, can foster job creation.

Cons

- Process innovation may displace labor and create technological unemployment.
- New products may displace older products and so impede the job-creation effects implied by the diffusion of the new activities.
- Market and institutional rigidities can impede the price and income compensation mechanisms that work to lessen job destruction.
- The job-creation impact of innovation is often limited to product innovation and to the high-tech sectors.
- Safety nets are necessary for the possible job losses due to process innovation in non-high-tech sectors.

AUTHOR'S MAIN MESSAGE

R&D expenditures that result in product innovation are generally labor-friendly, while the direct impact of research expenditures that result in process innovation are generally labor-saving. Industrial and innovation policies that support research and product innovation, especially in high-tech sectors, can lead to the emergence of new firms and new sectors—and new jobs. Meanwhile, any initial displacement of workers as a result of process innovation can be countered by indirect price, investment, and income compensation mechanisms that reduce the direct job-destroying impact of innovation. Thus, R&D investments, especially in high-tech sectors, may not only foster competitiveness, but may also be an effective means of creating jobs.

MOTIVATION

The relationship between technology and employment has long been a subject of debate. Claims of technologically-caused unemployment tend to re-emerge at times of radical technological change such as countries are currently experiencing.

Today, debate focuses on three main questions: What are the roles of technology and innovation in explaining the long-term declining trend of manufacturing as a share of the modern economy? Is innovation the main culprit behind the persistent unemployment currently affecting many advanced and developing economies? Are job losses due mainly to the current economic crisis, or can they be considered structural and therefore inevitable?

This paper discusses the possible labor-saving impact of technological change, on the one hand, and the scope for job creation on the other hand, focusing in particular on the market and institutional mechanisms that can shape the final labor demand outcomes.

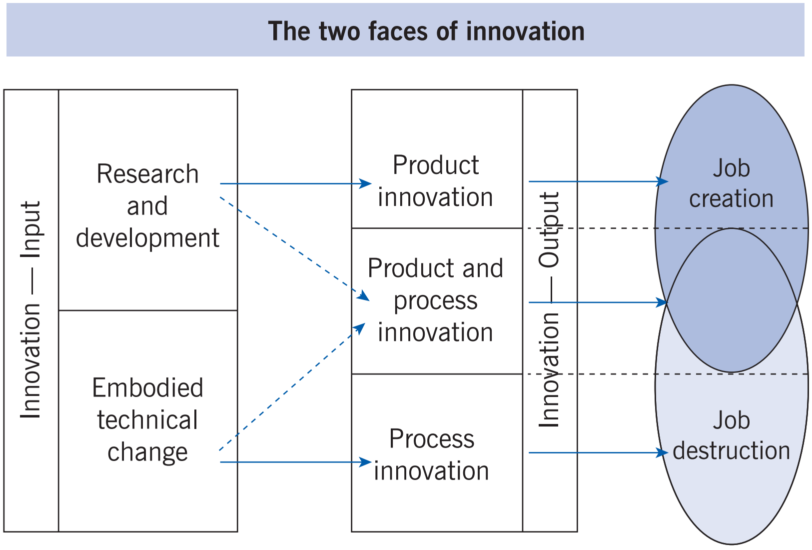
DISCUSSION OF PROS AND CONS

One of the main drivers of the long-term deindustrialization trend in developed countries is the productivity gap between manufacturing and services. Technological change is singled out as the main determinant of the productivity improvements that entail job losses in manufacturing and that therefore lead to the declining share of industrial employees in total employment. More recently, there has also been the striking emergence of labor-saving technologies in service industries ranging from the financial sectors to trade and retail.

There are two main types of technological change and innovation: research and development (R&D), which can lead to product innovation, and embodied technological change, which leads to process innovation. R&D investments are the key innovation input in the approach originally proposed in 1979 by Zvi Griliches, who identified the concept of the "knowledge production function." In this functional relationship linking innovative inputs to innovative outputs, firms pursue new economic knowledge as an input into generating innovative activities. Indeed, a vast literature has identified a strong significant link between R&D investment, innovation, and productivity gains, demonstrating that R&D is a main driver of technological progress at macroeconomic, sectoral, and microeconomic levels. Meanwhile, embodied technological change involves process innovation, or innovation that is incorporated in investments in capital goods (machinery and equipment) [1]. The innovation literature suggests that it is mainly large high-tech firms that rely on formal R&D to drive complex product innovation, while embodied technological change plays a key role in small- and medium-size firms in more traditional industrial sectors [2]. Thus, of the two main drivers of technological change, R&D is related to product innovation, and embodied technological change is more closely related to process innovation.

In some circumstances, the distinction between product innovation and process innovation is ambiguous from an empirical point of view (consider, for instance, the diffusion of computers and telecommunication devices), and in many cases the two forms of innovation are interrelated as both innovation inputs and innovation outputs. Both R&D and embodied technological change participate in mixed innovative activities that entail both product and process innovation. Figure 1 illustrates the main links between innovative inputs and innovative outputs.

Figure 1. The two faces of innovation: how product and process innovation affect employment



Source: Author's own illustration.

Process innovation and product innovation have different general relationships with employment (as shown in the far-right panel of Figure 1). Process innovation results in a direct labor-saving (job-destroying) effect, related mainly to the introduction of machinery and equipment that can substitute for labor and allow the production of the same amount of output with fewer inputs (generally workers). Product innovation can entail a job-creating effect through the emergence of new products and new markets.

The labor market implications of process innovation

Since by definition process innovation means producing the same amount of output with less labor (and sometimes other) inputs, the direct impact of process innovation is job destruction when output is fixed. However, economic analysis has demonstrated the existence of countervailing economic forces that can compensate for the reduction in employment arising from technological progress. Classical economists put forward a theory that Marx later called the "compensation theory." Technological change can trigger various market compensation mechanisms that can counterbalance the initial labor-saving impact of process innovation [3], [4], [5], [6]. These compensation mechanisms include new machinery, lower prices, new investments, and lower wages.

The compensation mechanism of new machinery

The effect of the compensation mechanism operating through new machinery (embodied technological change) is ambiguous. On the one hand, process innovations displace workers in downstream industries that introduce the embodied technological change incorporated in the new machinery. On the other hand, additional workers are needed in the upstream industries that produce the new machinery.

However, there are at least three arguments against the efficacy of this compensation mechanism. First, for the introduction of the new machinery to be profitable, the cost of labor associated with the construction of the new machinery has to be lower than the cost of labor displaced by the new capital goods. Second, labor-saving technologies spread to the capital goods sector as well as to the product sector, so this compensation can be an endlessly repeating story, with only partial labor compensation. Third, and most important, the new machinery can be implemented through either new investments or by the replacement of obsolete machinery (scrapping). In the case of scrapping obsolete machinery, which is the most common method, there is no compensation at all for resulting job losses [3], [4].

The compensation mechanism of lower prices

While process innovations destroy jobs, the changes that they introduce lead to declining average costs. Assuming perfect competition, this effect is translated into lower prices, which in turn imply rising demand and therefore additional production and employment [5].

However, this line of reasoning does not take into account possible demand rigidities. For instance, pessimistic expectations by firms may delay expenditure decisions, resulting in lower demand elasticity. In that case, the compensation mechanism of lower prices fails to operate as expected, and technological unemployment becomes structural. In fact, since process innovations are continuously introduced into the economy, a delay in expenditure decisions is sufficient to create a component of unemployment that persists over time [4].

Finally, the effectiveness of the mechanism that plays out through lower prices depends on the assumption of perfect competition. In an oligopolistic market, this compensation mechanism is severely weakened since cost savings are not necessarily or entirely translated into lower prices [4], [5].

The compensation mechanism of new investments

If the assumption of perfect competition is dropped, the decline in costs resulting from technological advances is not necessarily or immediately followed by falling prices. That means that the innovative firm can reap extra profits. If these extra profits are re-invested in the firm, this investment can create new jobs [5].

However, this compensation mechanism through new investments is based on another assumption: accumulated profits due to innovation are entirely and immediately translated into additional investments. In fact, because of cautious expectations, a firm may decide to postpone any new investments. In that case, again, a substantial delay in realization of this compensation mechanism may imply structural unemployment.

Moreover, the nature of any new investment is important. If the investments are capital- rather than labor-intensive, compensation for job losses through investment can only be partial [3], [4], [6].

The compensation mechanism of declining wages

In a so-called partial equilibrium framework that considers equilibrium of demand and supply only within the labor market (rather than dynamically, within the economy as a whole), the direct effect of labor-saving technologies may be compensated for within the labor market itself. Under the assumption again of perfect competition and full substitutability between labor and capital, technological unemployment leads to a decline in wages as a consequence of an excess supply of labor, and this impact in turn induces a shift back to more labor-intensive technologies.

However, countering this compensation mechanism of falling wages is the Keynesian theory of “effective demand.” While falling wages might be expected to induce firms to hire additional workers, it may also be the case that the shrinking of aggregate demand as a result of falling wages could lower employers’ business expectations and so their willingness to hire additional workers.

Moreover, this compensation mechanism assumes perfect substitutability between capital and labor, which is often not the case, especially under conditions of cumulative and irreversible technological progress [1], [3].

On balance

These market compensation mechanisms emerge as powerful forces counterbalancing the initial job destruction impact of process innovation. However, the functioning of these mechanisms is impeded by many institutional and market forces that can greatly weaken their efficacy. Eventually, determining how effective these mechanisms are is a matter for empirical analysis (see below).

Product innovation

The picture is far clearer in the case of product innovation than of process innovation. Obviously, the introduction of new products and the consequent emergence of new markets will have job-creation effects. Consider, for example, how many direct and upstream and downstream jobs were created as a result of the invention of the automobile at the beginning of the 20th century or of the personal computer later in that century. Classical economists emphasized the labor-intensive impact of product innovation, and even the most severe critics of an optimistic vision of the employment consequences of technological change have admitted that product innovation leads to large, positive employment effects.

The current debate on product innovation focuses on how product innovation implies the creation of jobs because innovation results in the development of new goods and even in the emergence of entirely new sectors [4], [7].

However, though incontrovertible, the labor-friendly impact of product innovation may be stronger or weaker, depending on the circumstances. Indeed, the “welfare effect” of product innovation (the creation of new goods) needs to be balanced against the “substitution effect” (the displacement of mature products by new ones: think, for instance, of how smartphones have replaced cameras, music players, fax machines, and even computers) [7]. In other words, different technological advances result in different families of new products, which in turn may have different effects on employment. For example, while the introduction of the automobile at the beginning of the 20th century and the diffusion of home computers at the end of that century both clearly had job-creating effects, automobiles had a much greater labor-intensive impact than home computers [1], [7].

Empirical evidence

As the discussion to this point has indicated, theoretical models do not provide clear-cut answers about the final employment impact of technological change. For that, empirical analyses are needed that can take into account the various forms of technological change, their direct effects on labor, the different compensation mechanisms at play in process innovation, and the likely impediments to these mechanisms.

Very few macroeconometric studies have tried to test the validity of compensation mechanisms through aggregate empirical studies conducted within a general equilibrium framework. One study estimated the direct labor-saving effect of process innovation, various compensation mechanisms (with their transmission channels and their possible drawbacks), and the job-creating impact of product innovation for two advanced Western economies, Italy and the US, over 1960–1988 [3], [4]. The study found that the most effective compensation mechanism for limiting employment losses in both countries was falling prices; other mechanisms were less important. Moreover, the US economy was more product-oriented, as evident in an overall positive relationship between technological change and employment, than the Italian economy, where the various compensation mechanisms were unable to counterbalance the direct labor-saving effect of widespread process innovation [4].

A more recent study uses the number of triadic patents (a set of linked patents at the European, Japanese, and US patent offices) in 21 industrial countries issued over the period 1985–2009 as an innovation indicator for assessing the impact of innovation on the aggregate unemployment rate [8]. The results show that technological change tends to increase unemployment, although this effect does not persist in the long term.

In principle, the ideal setting to fully investigate the link between technology and employment is a macroeconomic empirical model that jointly considers the direct effects of process and product innovation and all the indirect income and price compensation mechanisms discussed above. In practice, however, such empirical macroeconomic exercises are very difficult to arrange. They are also controversial, for several reasons. First, measuring aggregate technological change is problematic. Second, the analytical complexity required to represent the various compensation mechanisms makes interpreting the aggregate empirical results extremely complicated. And third, composition effects (in terms of sectoral input–output linkages) and the behavior of individual firms may render the macroeconomic assessment unreliable or meaningless. For these reasons, and because of the recent availability of reliable longitudinal data sets, the sectoral and microeconomic literature on the link between innovation and employment is larger and flourishing.

The sectoral dimension is particularly important in investigating the overall employment impact of innovation. In particular, the compensation mechanism that works through new outputs—which today more often takes the form of compensation through new services rather than new products—may accelerate the secular shift from manufacturing to services [4].

In manufacturing, new technologies seem to be characterized mainly by labor-saving embodied technological changes that are only partially compensated for by market mechanisms. For instance, a study of Italian manufacturing found a negative relationship between productivity growth and employment, with product and process innovation having opposite effects on the demand for labor. This finding is in line with that of another study that showed that for the Italian economy, various compensation mechanisms were unable to counterbalance the direct labor-saving effect of widespread process innovation, as discussed above [4].

More recently, a study used data on four manufacturing sectors across German regions for 1999–2005 to examine the co-evolution of R&D expenditures, patents, and employment [9]. The main finding was that patents (innovation) and employment are positively and significantly correlated in two high-tech sectors (medical and optical equipment and electrics and electronics) and not correlated in the other two more traditional sectors (chemicals and transport equipment).

Several recent microeconometric studies have fully taken advantage of the newly available longitudinal data sets to apply panel data econometric methods that jointly take into account both the time dimension and the cross-section individual variability. For example, one study matched the London Stock Exchange database of manufacturing firms with the innovation database of the Science Policy Research Unit at the University of Sussex (SPRU) to create a panel of 598 British firms over 1976–1982 [10]. The study found a positive employment impact of innovation, a finding that remained even in several variations in model specifications.

Another study found evidence of a positive effect of innovation on employment at the firm level. In particular, after applying panel methodologies to a longitudinal data set of 575 Italian manufacturing firms over 1992–1997, the study found evidence of a small but significant positive link between a firm's gross investment in innovation and its employment (for an in-depth discussion, see [4] and [6]).

Using firm-level data obtained from the third wave of the Community Innovation Survey for France, Germany, Spain, and the UK, a study developed a testable model able to distinguish the employment impacts of process innovation and product innovation (proxied by discrete variables equal to either zero or one) [11]. The study concluded that process innovation tends to displace employment, while product innovation is basically labor-friendly (see also [4]).

A recent study, using a dynamic employment model and a longitudinal data set on German manufacturing firms over the period 1982–2002, found a significantly positive impact of various current and past product and process innovation variables on labor demand [12]. Thus, innovation in these cases was employment-friendly.

Finally, a study using a panel database covering 677 European manufacturing and service firms over 19 years (1990–2008) detected a positive and significant employment impact of R&D expenditures only in services and high-tech manufacturing but not in the more traditional manufacturing sectors [13]. In the more traditional manufacturing sectors, the employment effect of technological change is not significant.

On the whole, recent microeconometric studies—especially those based on reliable panel data—offer a detailed mapping of the possible job-creating impact of innovation. Together, they reveal that positive employment effects are generally limited to the high-tech sectors, characterized by a higher R&D intensity and by the prevalence of product innovation.

LIMITATIONS AND GAPS

Theoretical models cannot claim to have a clear answer on the final employment impact of process and product innovation.

While the price and income mechanisms described here have the potential to compensate, fully or in part, for the direct labor-saving impact of process innovation, the precise outcome is uncertain. Determining factors include such variables as the degree of competition, demand elasticity, elasticity of substitution between capital and labor, and expectations of consumers and employers. Overall, depending on market structure and institutional contexts, compensation mechanisms can be more or less effective, and the unemployment impact of process innovation can be totally, partially, or not at all neutralized.

Similarly, the findings of empirical studies are not fully conclusive about the possible employment impact of innovation and technological change. Most recent panel investigations support a positive link. This positive link is especially evident when R&D or product innovation are adopted as proxies for technological change and when the focus is on high-tech sectors and high-growth firms [4], [6]. In many sectors, however, especially in services, product and process innovation are intermingled and difficult to disentangle. Moreover, while process innovations display clear direct labor-saving effects, some product innovations may also involve job displacement. Therefore, it is not always easy and straightforward to design industrial and innovation policies that can effectively maximize the positive employment impact of innovation. Additional microeconometric studies of the type addressed by the current research literature are needed to further disentangle the labor impact of innovation across different sectors and different types of firms.

SUMMARY AND POLICY ADVICE

The literature, both theoretical and empirical, has examined the main technological drivers that can play a role in the loss of manufacturing jobs and the creation of massive unemployment. Technological innovation affects the economy through both process and product innovation, both of which can have employment impacts. For the most part, R&D expenditures that result in product innovation are generally labor-friendly, creating new jobs, while embodied technological change that results in process innovation is generally job-destroying. A clear policy implication would seem to be that economic policy should try to foster job creation by supporting R&D investments and product innovation.

However, the picture is more complicated than that. Product and process innovation are often interrelated, and process innovation does not always lead to job destruction. Indeed, much of the theoretical literature on the employment impact of technology has focused on various market compensation mechanisms that can counteract most if not all of the technological unemployment impacts of process innovation.

Thus, a general theoretical and empirical conclusion is that compensation mechanisms are always at work but that the full reabsorption of workers dismissed as a result of technological change cannot be assumed ex ante. In particular, to work properly, compensation mechanisms require competition (to facilitate the compensation mechanism that works through lower prices), optimistic expectations (to facilitate the compensation mechanisms that work through lower prices and new investments), and a high elasticity of substitution between capital and labor. In this framework, competition policies that lower entry barriers and reduce monopolistic rents, along with expansionary policies targeting intermediate and final demand for new products, can be important drivers of job creation.

Since economic theory offers no clear-cut answer on the employment effect of innovation, answers need to come from empirical analyses. Empirical studies can consider different forms of technological change, their direct effects on employment, various compensation mechanisms at work, and any possible impediments to these mechanisms.

In particular, microeconometric studies have the great advantage of enabling direct and precise firm-level mapping of input and output innovation variables [4], [6]. On the whole, the empirical literature, particularly the most recent microeconometric panel data analyses, tends to support a positive link between technological advances and employment, especially when the focus is on R&D and product innovation in high-tech firms. These positive employment outcomes of evidence-based studies are consistent with a lifecycle view of different industries, with emerging sectors characterized by product innovation (mostly labor-friendly) and more traditional, mature industries more likely to experience process innovation (mostly labor-saving).

By being reassuring about the possible positive employment consequences of increasing R&D investment across EU countries, this evidence supports the Europe 2020 policy target aimed at increasing the ratio of R&D to GDP across Europe. Indeed, the evidence from the microeconometric literature substantiates the view that R&D expenditures are beneficial not only to European productivity and competitiveness, but also to European job-creation capacity.

However, while supporting R&D investments and promoting emerging and high-tech sectors can be a means of fostering competitiveness, economic growth, and job creation, both industrial policies and innovation policies need carefully to take into account a series of complex interactions between process innovation and product innovation, between mature sectors and new sectors, and between job-creation and job-destruction effects. These complex interrelationships, difficult to predict in advance, highlight the need for continuous monitoring of policy implementation.

Acknowledgments

The author thanks two anonymous referees and the IZA World of Labor editors for many helpful suggestions on earlier drafts. Previous work of the author contains a large number of background references for the material presented here and has been used intensively in all major parts of this article [3], [4], [5], [6].

Competing interests

The IZA World of Labor project is committed to the *IZA Guiding Principles of Research Integrity*. The author declares to have observed these principles.

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