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Abstract

This note explores the theoretical and empirical literature on the link between innovation and employment, investigated at the macro, sectoral and micro level. While economic theory cannot provide a clear answer to the question whether new technologies are labor-saving or labor-friendly, most of the empirical studies point to a positive relationship between innovation and employment. Yet, this effect turns out to be small in magnitude and limited to product innovation and high-tech sectors, while labor saving impacts can be detected in the downstream more traditional sectors and firms.

Keywords: Innovation, technological change, employment, job-creation, job-destruction, technological unemployment.

JEL classification: O33

1 Introduction

Nowadays, the world is on the edge of a new technological revolution dramatically accelerated in the direction of automation by the pervasive diffusion of robots and Artificial Intelligence (AI) (Acemoglu and Restrepo 2019; Brynjolfsson and McAfee 2014; Frey and Osborne 2017). Henceforth, the fear of massive technological unemployment characterizes the current debate.

Indeed, the relationship between technological change and employment is a "classical topic" and the debate about the possible occurrence of "technological unemployment" cyclically comes out in ages of both radical technological change and considerable unemployment levels, such as the current one (Staccioli and Virgillito, 2021). However, in the history of humanity, periods of intensive automation have often coincided with the emergence of new jobs, tasks, activities and industries. Indeed, the challenging question is related to the overall impact of innovation on the level of employment: is technology labor-friendly or labor-threatening?

Given this context, this note critically presents theories and updated evidence on the link between technological change and employment; in particular, Section 2 is devoted to the theoretical framework; Section 3 to the available empirical evidence and finally Section 4 briefly concludes.

2. Theory

To evaluate the overall effect of technological change on employment, different direct and indirect mechanisms have to be taken into account. In general, the innovative effort is focused at reducing production costs as it happens in the case of process innovations. The aim is producing the same amount of output reducing the use of production inputs, namely labor; therefore, the very first direct effect of a process innovation is labor-saving, by definition.

However, when a process innovation is introduced, there might be potential market compensation mechanisms which may counterbalance the initial labor-saving impact of innovation (Freeman et al. 1982; Freeman and Soete 1987; Simonetti et al. 2000; Vivarelli 1995 and 2015). These countervailing forces can be classified as follows.

- Compensation via new machines. If new machines (say robots) are adopted widely, they might replace workers in some or all of their tasks. Nevertheless, in order to have robots available, additional production is needed. As a consequence, a sectoral shift of workers from the downstream robot-using industry towards the upstream robot-producing sectors may counterbalance the initial negative effect on employment (Dosi et al. 2021).

However, there are at least three counter-arguments with regard to this mechanism. Firstly, profitability requires that the cost of labor associated with the construction of the new machineries has to be lower than the cost of labor displaced by the new capital goods. Secondly, labor-saving technologies spread around in the capital goods sector, as well; so this compensation can be seen as an endless story, entailing a labor compensation which can only be partial. Thirdly and more important, the new machines can be implemented either through additional investments or simply by substitution of the obsolete ones (scrapping). In the latter case - which is indeed the most frequent one - there is no compensation at all (Vivarelli, 2013).

- Compensation via decrease in prices. The productivity increase determined by the broadly adoption of machineries and robots able to run automated tasks might induce a decline of the average production costs. This effect, under the strong assumption of highly competitive markets, can be translated into a subsequent reduction of prices. Lower prices should determine a higher demand which might induce new hiring for labor in non-automated tasks (Acemoglu and Restrepo 2018).

Obviously enough, this line of reasoning does not take into account possible demand rigidities: for instance, pessimistic expectations by investors and households may involve a delay in expenditure decisions and a lower demand elasticity. If such is the case, this compensation mechanism is dramatically hindered and technological unemployment becomes structural: in fact, since process innovation are continuously introduced in the economy, a delay in compensation is sufficient to create a component of unemployment that persists over time. Moreover, 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 is strongly weakened since cost savings are not necessarily and entirely translated into decreasing prices (Vivarelli, 1995 and Feldmann, 2013).

- Compensation via re-investment of extra-profits. The accumulated extra-profits which may emerge in non-perfectly competitive markets (where the elasticity between decreased unit costs and subsequent decreasing prices is less than one, limiting the scope of the previous mechanism) may be invested into capital formation, expanding both the productive capacity (supply) and the intermediate demand, in both cases implying an increase in employment.

However, also this compensation mechanism (“via new investments”) is based on an apodictic assumption: that accumulated profits due to innovation are entirely and immediately translated into additional investments. In fact, cautious or even gloomy expectations (the so-called “animal spirits”) may involve the decision to postpone investment decisions; here again, a substantial delay in compensation may imply structural technological unemployment. Moreover, the intrinsic nature of the new investments does matter; if these are capital-intensive and labor-saving themselves, compensation can only be partial (Freeman and Soete, 1987; Vivarelli, 2015).

- Compensation via decrease in wages. With regard to the labor market, the technological unemployment generated by the initial labor-saving effect leads to an excess of labor supply which might determine a reduction of wages; the consequent labor demand increase is supposed to re-equilibrate the labor market and absorb the initial labor supply surplus.

This mechanism ("via decrease in wages") clashes against the Keynesian theory of "effective demand": while - in a partial equilibrium framework - one expects that a decrease in wages may induce firms to hire additional workers, in a general equilibrium framework it must also to be taken into account that the consequent decreasing aggregate demand may lower employers' business expectations and so their willing to hire additional workers (see above). Moreover, this mechanism assumes perfect substitutability between capital and labor and this is not often the case, especially when cumulative, irreversible, path-dependent and localized technological progress is going on (Atkinson and Stiglitz, 1969; Freeman and Soete, 1987; Capone et al. 2019).

- Compensation via new products. As emphasized by Schumpeter (1912), technological change cannot be reduced to the sole (potentially labor-saving) process innovation. Indeed, the introduction of new products entails the raise of new branches of production and stimulates additional consumption and employment. For instance, Acemoglu and Restrepo (2019) affirm that AI - since it is not just a narrow set of technologies with specific, pre-determined applications and functionalities - can be deployed for much more than automation. With AI applications creating new tasks for labor (for instance in education, healthcare, augmented reality), there would be potential gains in terms of labor demand.

However, even the labor-friendly nature of product innovation needs to be qualified. First, the intensity of its impact depends on the weight that new products have in the baskets of consumption and on the income elasticities of their demand. Second, those which are new products for those producing them might well represent efficiency enhancing processes for their users (robots are an example). Third, in order to exert a compensating effect, new products should not exclusively replace obsolete ones: if new products just cannibalize the sales of older ones, the net result might be ambiguous (Katsoulacos, 1986; Vivarelli, 1995).

Indeed, the economic theory does neither provide a clear-cut answer nor forecasts about the employment effect of technological change, since it depends on a number of factors, assumptions, parameters, elasticities, model calibrations. Therefore, theoretical models should be integrated by empirical studies.

3. Empirical studies

3.1 General evidence

Even referring to previous innovation waves such as the ICT revolution, the theoretical literature has been supplemented by a wide range of empirical analysis (for recent surveys, see Vivarelli 2014; Calvino and Virgillito 2018; Ugur et al. 2018; Mondolo, 2021). Overall, the learning lesson from previous empirical studies is that findings vary a lot depending on the level of analysis (whether firm, sector or macro), the proxies for technological change (whether embodied, such as investment in new physical capital, or disembodied, such as R&D expenditures), the country and time dimensions of the analysis.

As far as the aggregate empirical studies are concerned, very few macroeconometric studies have tried to test the validity of the compensation mechanisms within a general equilibrium framework.

In Vivarelli (1995) the direct labor-saving effect of process innovation, the different compensation mechanisms (with their transmission channels and their possible drawbacks, see above) and the job-creating impact of product innovation have been represented and estimated through a simultaneous equations model estimated over the period 1960-1988 (three stages least squares regressions) in Italy and the US. The author finds that the more effective compensation mechanism is that "via decrease in prices" in both countries, while other mechanisms turned out to be less important. Moreover, the US economy emerges to be more product oriented (and so originating an overall positive relationship between technological change and employment) than the Italian economy, where the different compensation mechanisms turn out to be unable to counterbalance the direct labor-saving effect of widespread process innovation (see also Simonetti, Taylor and Vivarelli, 2000].

In a more recent study, Feldmann (2013) uses as an aggregate innovation indicator the number of triadic patents in 21 industrial countries over the period 1985-2009, to assess the impact of innovation on the aggregate unemployment rate. His results shows that technological change tends to increase unemployment, although this effect does not persist in the long run.

In principle, the macroeconomic empirical studies are the ideal setting to fully investigate the link between technology and employment, jointly considering the direct effects of process and product innovation and all the indirect income and price compensation mechanisms discussed above. However – in practice – the macroeconomic empirical exercises are very difficult to put forward and somehow controversial for different reasons: firstly, there are problems in measuring aggregate technological change; secondly, the analytical complexity to represent the various compensation mechanisms makes the interpretation of the aggregate empirical results extremely complicated; last, but not least, composition effects (in terms of sectoral belonging and single firms' behavior) may render the macroeconomic assessment either unreliable or meaningless. This is why - also thanks to the availability of new reliable longitudinal data - nowadays the sectoral and particularly the microeconomic literature on the link between innovation and employment is flourishing.

The sectoral dimension is particularly important in investigating the overall employment impact of innovation; in particular, the compensation mechanism "via new product" (which in recent times generally takes the form of a compensation "via new services") may accelerate the secular shift from manufacturing to services. On the other hand, in manufacturing new technologies seem to be characterized mainly by labor-saving process innovation, only partially compensated by the market mechanisms discussed above.

For instance, Vivarelli, Evangelista and Pianta (1996) have shown that in Italian manufacturing the relationship between productivity growth and employment appeared to be negative and, in particular, that product and process innovation had opposite effects on the demand for labor, in line with what discussed above.

More recently, Buerger, Broekel and Coad (2010) – using data concerning four manufacturing sectors across German regions over the period 1999-2005 – have studied the co-evolution of R&D expenditures, patents and employment through a VAR methodology. Their main result is that patents and employment turned out to be positively and significantly correlated in two high-tech sectors (medical and optical equipment and electrics and electronics), while not significant in the other two more traditional sectors (chemicals and transport equipment).

Turning our attention to the wider microeconometric literature, since the late '90s studies have fully taken the advantage of new available longitudinal datasets and have applied panel data econometric methodologies, that jointly take into account the time dimension and the individual variability.

For example, Van Reenen [1997] has matched the London Stock Exchange database of manufacturing firms with the SPRU (Science Policy Research Unit at the University of Sussex) innovation database and obtained a panel of 598 British firms over the period 1976–1982. The author finds a positive employment impact of innovation and this result turned out to be robust after controlling for fixed effects, dynamics and endogeneity.

Applying a similar approach, Piva and Vivarelli (2005) have also found evidence in favor of a positive effect of innovation on employment at the firm level. In particular - applying panel methodologies to a longitudinal dataset of 575 Italian manufacturing firms over the period 1992–1997 - the authors provide evidence of a significant, although small in magnitude, positive link between firm's gross innovative investment and employment.

In a similar methodological fashion, Lachenmaier and Rottmann (2011) have proposed a dynamic employment equation extended to include alternative proxies (mainly dummy variables) of current and lagged product and process innovation. Their regressions – based on a longitudinal dataset of German manufacturing firms over the period 1982-2002 – show a significantly positive impact of various innovation variables on labor demand.

However, Bogliacino, Piva and Vivarelli (2012) – using a panel database covering 677 European manufacturing and service firms over 19 years (1990-2008) – have found that a positive and significant employment impact of R&D expenditures is clearly detectable only in services and high-tech manufacturing but not in the more traditional manufacturing sectors, where the employment effect of technological change is not significant.

Also using firm level data (obtained from the third wave of the CIS) from four European countries (Germany, France, UK, Spain), Harrison et al. (2014) put forward a testable model able to distinguish the relative employment impact of process and product innovation. The authors conclude that process innovation tends to displace employment, while product innovation is basically labor friendly.

Van Roy et al (2018) have investigated the possible job creation effect of innovation activity, proxied by patents by almost 20,000 European companies over the period 2003–2012. The main outcome of their panel estimations is the labor-friendly nature of innovation. However, this positive impact of innovation turns out to be statistically significant only for firms in the high-tech manufacturing sectors, while not significant in low-tech manufacturing and services.

Finally, more recent studies have used longitudinal data but a more comprehensive measure of embodied technological change, which also includes robots (see Barbieri et al., 2018; Pellegrino et al., 2019; Dosi et al., 2021). While in these works the labor-friendly nature of R&D expenditures and product innovation is confirmed (consistently with the previous evidence), a possible overall labor-saving impact of embodied technological change incorporated in process innovation is also detected.

On the whole, the microeconometric literature offers a detailed mapping of the possible job-creating impact of innovation, revealing that it is small in magnitude and generally limited to the high-tech and upstream sectors, characterized by an higher R&D intensity and by the prevalence of product innovation. On the other hand, technological change embodied in process innovation may generate technological unemployment, particularly in the downstream and more traditional sectors.

3.2 AI and robots

As far as the specific employment consequences of the current widespread diffusion of AI and robots are concerned, the empirical literature provides both macroeconomic forecasting scenarios and some sectoral and microeconomic evidence.

As far as the macro scenarios are concerned, Frey and Osborne (2017), using a Gaussian process classifier applied to data from O*Net and the US Department of Labor, predict that 47% of the occupational categories, mostly middle- and low-skilled professions, are at high risk of being substituted by AI algorithms and robots (including a wide range of service/white-collar/cognitive tasks such as accountancy, health professions, logistics, legal works, translation and technical writing).

However, Arntz et al. (2016), proposing the same exercise but using also information on task-content of jobs at individual-level, conclude that only 9% of US jobs are at potential risk of automation. Their main message is that, within the same occupation, some tasks can be automatized while others cannot and therefore the associated job can be preserved.

Extending the analysis to a multi-country approach, Nedelkoska and Quintini (2018) estimate the risk of automation for individual jobs in 32 OECD countries. Their evidence shows that about 14% of jobs are highly automatable (probability of automation over 70%), while another 32% of jobs present a risk of being substituted in between 50 and 70%, pointing to the possibility of significant changes in the way these jobs will be carried out as a result of automation.

At the European level, Pouliakas (2018) - using data on tasks and skill needs collected by the European Skills and Jobs Survey (ESJS) - bundles jobs according to their estimated risk of automation. Following Frey and Osborne (2017) and Nedelkoska and Quintini (2018), the author utilises highly disaggregated job descriptions and shows that 14% of EU adult workers are found to face a very high risk of automation.

Turning our attention to the sectoral evidence, the extant empirical literature has particularly focused on robots, considered as the major drivers of automation (Montobbio et al., 2022).

For instance, Acemoglu and Restrepo (2020) investigate the employment effect of the exposure to robots, using the sectoral "International Federation of Robotics" (IFR) data (national penetration rates instrumented by European data). According to their 2SLS estimates, robotization has a significant negative impact on the change in employment and wages in each US local labour market over the period 1990 -2007. In more detail, they show that one more robot per thousand workers reduces the employment/population ratio by about 0.18/0.34%.

Following the approach adopted by Acemoglu and Restrepo, Chiacchio et al. (2018) apply it in the context of EU labour markets. They assess the impact of industrial robots on employment and wages in 116 NUTS regions of six EU countries, namely Finland, France, Germany, Italy, Spain, and Sweden, largely representative of the European automation. Their results suggest that robot introduction is negatively associated with the employment rate (one more robot per thousand workers reducing the employment/population ratio by about 0.16/0.20%).

Graetz and Michaels (2018) use panel data on robot adoption (IFR and EUKLEMS data to estimate robot density) within industries in 17 countries from 1993 to 2007. Dividing employees in three skills' groups (namely high-, medium- and low-skilled workers), their estimated employment coefficients for the two higher-skilled groups result positive (but limited in magnitude and not always significant), while the coefficient for the low-skilled workers turns out to be large and negative. However, their main finding is at odds with the studies discussed above since they conclude that robots do not significantly reduce total employment, although they do reduce the low-skilled workers' employment share.

Finally, Dauth et al. (2017) propose a local empirical exercise on Germany using IFR data over the 1994-2014 time-span, using a measure of local robot exposure for every region. They find no evidence that robots cause total job losses, although they provide evidence that robots do affect the composition of aggregate employment: while industrial robots have a negative impact on employment in the manufacturing sector, there are positive and significant spillover effects as employment in the non-manufacturing sectors increases and, overall, counterbalances the negative impact in manufacturing.

Shifting to studies using firm-level data, results are conflicting. Domini et al. (2020), using robotic adoption or, alternatively, imported capital equipment, does not detect labour expulsion, but rather employment growth. Interestingly enough, in some studies the positive employment impact at the firm level appears entirely due to the so-called "business stealing effect" – i.e. innovative adopters gain market shares at the expense of non-innovators (Dosi and Mohnen, 2019) – since negative employment impacts do emerge once non-adopters and sectoral aggregates are taken into account (see Acemoglu et al., 2020; Koch et al., 2021).

4. Summary and conclusions

In this note, I have discussed – from a theoretical and an empirical point of view – the main technological drivers which can play a role in determining the eventual employment impact of new technologies. I started from the different ways how technology is implemented into the economy (process *vs* product innovation), and then I moved to the discussion of its direct and indirect effects on employment, taking into account the different market compensation mechanisms and the possible market failures which can severely hinder their efficacy. In this framework, a first conclusion is that economic theory cannot provide a clear answer to the question whether new technologies are labor-saving or labor-friendly.

Indeed, while compensation is always at work, the full reabsorption of the dismissed workers cannot be assumed ex-ante. In particular, compensation requires competition (to facilitate the mechanism via decrease in prices), optimistic expectations (to facilitate both the mechanism via decrease in prices and the compensation via new investments) and a high elasticity of substitution between capital and labor.

Since economic theory does not have a clear-cut answer about the employment effect of innovation, there is a strong need for empirical analyses. In particular, microeconometric studies have the great advantage to allow a direct and precise firm-level mapping of innovation variables, both in terms of inputs and outputs.

On the whole, the empirical literature 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 and when high-tech sectors are focused on.

Therefore, policy makers should be confident that supporting R&D investments and promoting emerging and high-tech sectors is not only a way to foster competitiveness and economic growth, but also an effective measure to foster job creation.

Obviously enough, both industrial and innovation policies should also cautiously take into account the complex interlinks between process and product innovation, between mature and new sectors and finally between job-creation and job-destruction effects. As showed in the very recent Dosi et al. (2021), R&D-based job creation in the upward sectors may well co-exists with labor saving impacts in the downstream sectors, due to the implementation of the new technologies (embodied technological change) provided by the upstream sectors (for instance robots). These complex relationships make the policy design extremely complicated and raise the need for a continuous monitoring of the implemented policies.

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