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THE INNOVATION-EMPLOYMENT NEXUS: A CRITICAL SURVEY OF THEORY AND EMPIRICS

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Abstract. Understanding whether technical change is beneficial or detrimental for employment is at the center of the policy debate, especially in phases of economic recession. So far, the effects of innovation – in its manifold declinations and intrinsic complexity – on labor demand have proven to be not unequivocal. This essay critically reviews the role of technical change in shaping employment dynamics at different levels of aggregation. First, it disentangles theoretically the role of different compensation mechanisms through which employment adjusts after an innovation is introduced. Second, it critically presents the most recent empirical evidence on the topic, with a focus on methods and limitations. Finally, it provides an attempt to conceptualize a number of stylized facts and empirical regularities on the innovation-employment nexus.

Keywords. Compensation mechanisms; Innovation; Technological unemployment

1. Introduction

The nexus between technology, innovation, and employment is a central area of investigation from both a theoretical and empirical perspective. It has a long tradition in economic research, starting from the Ricardian conceptualization of technological unemployment, moving to the Keynesian prediction on "mankind solving the economic problem" and culminating on the current debate on the effects of robotization and automation on different occupations. The complex nature of technological progress can be summarized, rephrasing Dosi (1982), as being both an *engine* and a *thermostat*. As an *engine*, it "gives" the rhythm at which a new technological paradigm enters into the market and evolves along its trajectory. As a *thermostat*, it "controls" the diffusion of its waves among different sectors.

Understanding whether technical change is beneficial or detrimental for employment – and consequently whether compensation mechanisms able to counterbalance the two opposing forces exist – is at the center of the policy debate, especially in the current economic recession. So far, the effects of innovation – in its manifold declinations and intrinsic complexity – on labor demand have proven to be difficult to discern. A comprehensive analysis that frames the nexus between technical change and employment, in the light of the most recent contributions, seems therefore necessary.

The aim of this essay is to critically review the role of technical change in shaping employment dynamics. First, this study theoretically disentangles the effects of different compensation mechanisms

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through which employment adjusts after an innovation is introduced. Second, it critically presents the most recent empirical evidence on the topic, with a focus on methods and limitations. Finally, it provides an attempt to conceptualize a number of stylized facts and empirical regularities on the innovation-employment nexus.

Both labor creation and labor displacement seem to be related to different kinds of innovative activities, such as product and process innovation. The distinction between "the introduction of new goods [...]" and the "introduction of a new method of production [...]" is particular to the Schumpeterian view. Certainly, as pointed out by Dosi (1984, p. 104), "in practice, product innovation of one sector are often process innovation for other sectors which are using them. The distinction nonetheless is theoretically fruitful." Pianta (2005) views the idea that labor destruction is a result of process innovation and labor-creation is a result of product innovation, through the mechanism of consumer demand via the opening of new markets, as too simplistic. In fact, as we will discuss in the following section, the introduction of new products could be to replace existing obsolete ones.

The innovation-employment nexus is determined not only by direct effects, but also by the "types" of compensation mechanism at work (and by the channels through which such mechanisms operate). Furthermore, the level of aggregation at which the relationship between employment and technical change is evaluated is critical. Features associated with different levels – namely, firm and sectoral – will be emphasized throughout the analysis.

The outline of this survey builds upon the works by Freeman *et al.* (1982), Vivarelli (1995), Spiezia and Vivarelli (2002), Pianta (2005), Vivarelli (2013) and Vivarelli (2014). It however departs from previous analyses in different respects: (i) it discusses the most recent firm-level and industry-level contributions, focusing on the last decades since the year 2000, with particular attention to differences in methodologies and limitations; (ii) it emphasizes the impact of the level of aggregation on the innovation-employment nexus; (iii) it investigates in detail the extent to which compensation mechanisms operate at the firm and industry level; (iv) it discusses the firm-industry linkage integrating results from shift and share decompositions of productivity on employment shares; and (v) it examines the effect of business cycles, and how they influence the innovation-employment relationship.

This study is organized as follows. The research questions and the theoretical background are presented in Section 2. In Section 3.1, we discuss the most recent empirical findings at the firm level; in Section 3.2 we focus on shift and share decompositions of productivity with employment shares; while in Section 3.3, we examine industry-level analyses. Section 4 proposes a number of stylized facts and Section 5 concludes and outlines the limitations of this work together with possible areas for further research.

2. The General Theoretical Framework

The relationship between innovation and employment is a key issue in economic theory. However, disentangling this nexus is particularly complex, both from a theoretical and an empirical perspective.

Our starting point is an enquiry on the alternative theoretical approaches, which can be classified in *equilibrium perspectives* (Neoclassical analyses) and *disequilibrium perspectives* (namely, Evolutionary, Keynesian, Structural, and Regulationist theories). The main disagreement between the two views is the possibility of a self-adjustment process that starts as soon as innovation is introduced. According to the former, higher innovation induces increases in productivity and therefore in the growth rate. The causal effect of innovation leads to higher employment, via an increase in total output and wages reduction. According to the latter, the effect of innovation on employment is difficult to discern, framing technological progress as a complex phenomenon.

Starting from different theories about the technology-employment nexus, this section goes through the analysis of the alternative *compensation mechanisms* proposed by distinct schools of thought, together with their limitations.

2.1 *Competing Theories on the Innovation-Employment Nexus*

How has the relation between innovation and employment evolved along the course of the economic thought? During the pre-Classical era, the Mercantilists seriously considered the potentially detrimental effect on employment associated with the introduction of new machineries. Particularly, as recorded by Freeman and Soete (1994), a number of regulations were introduced in France and England that attempted to control the use of machineries in the production process (i.e., limiting the use of calico or sewing machines). In the debate of that period, several proponents including James Steuart supported active protectionism of strategic industries by the government in order to avoid mass unemployment and social revolt.

The active interventionism of the Mercantilist approach was discarded after the diffusion of the so-called *laissez-faire* principles. According to this theory, the mechanization of labor would have spurred a subsequent reduction in prices, and thereby inducing a welfare enhancement in the long run, *compensating* for the initial labor displacement. Despite the pervasiveness of this argument among both economists and policy makers, David Ricardo was the most prominent Classical economist who questioned the long run benefit of technological innovation, stressing the labor-saving bias induced by new technologies:

> *That the opinion entertained by the labouring class, that the employment of machinery is frequently detrimental to their interests, is not founded on prejudice and error, but is conformable to the correct principles of political economy*. [Ricardo, 1817].

The quotation above suggests that a substantial debate was already taking place during the Classical period, and that a unifying theory on the relation between employment and innovation was strikingly missing. However, the possibility of temporal mismatches and the emergence of rigidities in the adjustment process – originating from the supply side (labor force) – had already been discussed in that period. Following Ricardo, the Marxian perspective also views technological advancement as being intentionally led by capitalists in order to increase unemployment, as mean of control on the labor force. The predominance of the Neoclassical view however diffused the idea of the existence of a self-equilibrating mechanism based on the cornerstone of the Say's Law.

Along with the general equilibrium view, the *principle of factors substitution* became one of the main pillars of economic analysis. According to this principle, the most profitable combination of labor and capital given current prices can be effectively pursued. Under market-clearing mechanisms, overproduction and unemployment are theoretically ruled out. Technological innovation can simply lead to *temporal* labor destruction. The possible mismatch is not due to the lack of job opportunities, squeezed by technical progress, but by the lack of a downward equilibrating salary, able to match the reduced demand for labor. By analyzing the series of subsequent effects, the relative capital depreciation induced by technological progress results in a lower interest rate, thereby fueling the investment activity. Two opposing forces interact in the market for capital: on the one hand, under decreasing returns to scale, the marginal productivity of capital decreases along with capital accumulation, reducing the related demand. On the other hand, the supply of capital tends to decrease, triggered by the low interest rate. The interest rate clears the market for capital. On the labor market, wages play the equivalent equilibrating role that interest rates play in the capital market.

The Keynesian approach was characterized by an alternative perspective to the "self-regulating system," circumscribing the validity of Say's law only to full-employment conditions. This popular version of the Keynesian perspective suggests that in situations of underemployment, without any external intervention in the market, there is no possibility to recover from stagnation-depression periods.

The major distinction between Keynes and Neoclassical economists can be primarily stated in terms of their theoretical view of the economic system, rather than in terms of the extent to which a State should intervene:

On the one side were those who believed that the existing economic system is in the long run self-adjusting, though with creaks and groans and jerks, and interrupted by time-lags, outside interference and mistakes. [...] Those on the other side of the gulf, however, rejected the idea that the existing economic system is, in any significant sense, self-adjusting. They believed that the failure of effective demand to reach the full potentialities of supply, in spite of human psychological demand being immensely far from satisfied for the vast majority of individuals, is due to much more fundamental causes. [BBC Radio address, 1934, reprinted as Keynes, 1963].

In the *General Theory*, unemployment is all but a temporary phenomenon and cannot be "solved" within the labor market. During the recession phase, the low level of aggregate demand will result in a lack of private investments, due to negative expectations on future profits. To boost the economy toward a recovery phase, aggregate demand has to be stimulated, reestablishing a period of positive investment expectations. Higher investment will translate into higher demand for labor, hence reducing unemployment. However, in the Keynesian framework, limited attention is devoted to the role of technical progress and to the introduction of labor-saving technologies.[1] In fact, Keynes develops a theory of booms and bursts led by investment. But investment mechanism, in the *General Theory*, is only connected to an undefined idea of profits expectations.[2] Unfortunately, the determinants of investment expectations are however not discussed in depth and "black-boxed" into the concept of "animal spirits." In this context, it is noteworthy to emphasize that the Keynesian view does not portray innovation as an engine of investment activity.

On the contrary, the Schumpeterian analysis has been notably direct in disentangling the role of innovation in shaping economic dynamics. In particular, it is built on the concepts of clustered innovation, product life cycle, imitation, and diffusion: the interplay of these elements determines the emergence of cycles or waves where periods of growth, due to the launch and diffusion of new products, alternate with periods of market saturation. Unemployment arises as a result of technological innovation, whose diffusion takes considerable time and affects different sectors asymmetrically. Innovation is seen as a painful process, which creatively destroys the old and opens the way for the new. Nevertheless, Schumpeter does not believe in the possibility of structural/Keynesian unemployment (see Dosi *et al.*, 1988).

The Schumpeterian legacy was passed on to neo-Schumpeterian/new growth theories, with a continuing emphasis on the supply side, as well as evolutionary-institutionalist theories. The latter, mainly endorsed by Chris Freeman, Carlota Perez, and Luc Soete, tries to refine the Schumpeterian idea of economic fluctuations by linking a notion of long swings – sometimes associated with Kondratieff long waves (Kondratieff and Stolper, 1935) – with the emergence of *technoeconomic paradigms*.[3] In this view, the establishment of a new technological paradigm (Dosi, 1982) occurs by means both of technological factors and institutional components. According to Freeman and Perez (1988), in the presence of misalignments between the technoeconomic conditions and the social environment, depressions arise. Broadly speaking, it is a matter of "waiting" for the reconjunction of the two sides. The Regulationist school, lead by Boyer (1988), takes a less deterministic perspective which categorized alternative *archetypes of capitalism* nested in the coupling between the *accumulation regimes* and the *modes of regulation*.

2.2 *On the "Compensation Mechanisms": Is There Any Self-Adjustment Process?*

As suggested in the previous section, different schools of thought conceptualize (or not) alternative channels that balance the effects of technical change on employment.[4] Freeman *et al.* (1982), Vivarelli (1995), and more recently Vivarelli (2013, 2014) have proposed a classification of the different compensation mechanisms in terms of the alternative "pass-through" channels that trigger the transmission chain of economic effects. Following this stream of literature, we distinguish between Classical-Neoclassical and Keynesian-Schumpeterian mechanisms.

Classical-Neoclassical mechanisms can be classified as follows:

- **New machines**. As the result of technical progress, new machines are introduced, possibly displacing labor. A "sectoral shift" of workers from the machine-using industry toward the machine-producing one counterbalances the initial detrimental effect on employment.
- **Decrease in prices**. The increase in productivity due to the introduction of new technologies induces a reduction in production costs. This effect in *competitive* markets induces a subsequent reduction in prices. Lower prices should translate into higher demand, and therefore higher employment.
- **Decrease in wages**. This mechanism acts in the market of production factors and exerts effects symmetric to the process of price reduction. Workforce displacement leads to an excess of labor supply, hence to a reduction in wages. An increase in labor demand reequilibrates the market tension which resulted from the first wave of excess labor supply.
- **New investments**. The accumulated extra-profits in the temporal gap between the decrease in the unit costs and the subsequent decrease in prices can be invested by entrepreneurs in physical capital, expanding the productive capacity and hence the labor demand.

Keynesian-Schumpeterian mechanisms can, instead, be categorized as follows:

- **Increase in incomes**. Whenever workers are able to appropriate gains from the increase in productivity, technical progress can lead to an increase in wages and consumption. This leads to higher demand, sparking an increase in employment via the well-known Keynesian mechanism, compensating for the initial labor displacement.
- **New products**. The introduction of new branches and products can stimulate consumption. Higher consumption translates into higher demand and therefore higher employment. Under the traditional Schumpeterian distinction between product and process innovation, the former is recognized to be labor-friendly while the latter as labor-displacing. However, in order to exert a compensating effect, new products should not exclusively to replace obsolete ones. In this respect, at the firm level, new products can *cannibalize* sales of old products, resulting in ambiguous net effects. Furthermore, at the industry level, product innovators may face a demand increase via *market expansion* as the new product might satisfy consumers' previously unmet needs. This effect is positive on employment. On the other hand, product innovators can erode market shares of noninnovators via the so-called *business stealing* effect, as old products become obsolete.[5] Finally, one should not forget that new products may be produced more efficiently, due to the complementarities existing between product and process innovation strategies.

Unfortunately, the effectiveness of the aforementioned compensation mechanisms is all but deterministic: many aspects intertwine, undermining the possibility of any ex ante exhaustive prediction about their relative efficacy. Therefore, it is necessary to consider a number of possible limitations.

Concerning the introduction of new machines, there is nothing that prevents mechanization from moving across sectors. The structural change from agriculture to manufacturing, and from the latter to services, is a clear example of the spread of technical change across sectors. Even though the direction of the rate of absorption of the workforce moved from the first two sectors toward the third, nowadays part of the service sector is experiencing a strong reduction in labor demand. In addition, the higher the rate of technical change, the higher the rate of obsolescence of machineries, inducing scrapping and substitution. If the introduction of new machines merely replaces those which are obsolete, no compensation would arise.[6]

The compensation mechanism via a decrease in prices must counterbalance the reduction in aggregate demand associated with workers dismissal in order to function properly. Necessary conditions for its effectiveness include: (i) significant price elasticity for the commodities that are affected by the price reduction; (ii) high relevance of these commodities in workers' consumption bundles; and (iii) nonoligopolistic market structures. The extent to which the composition of aggregate demand is affected by price reductions therefore depends on whether the above conditions are fulfilled. Limited validity of such conditions can result in unchanged – or even reduced – aggregate demand.

A similar framework would also apply to the wage reduction channel. However, this mechanism is additionally based on the principle of factor substitution. A number of theoretical flaws can undermine its effectiveness. They include: (i) the fact that technology is not time-reversible: if a firm masters a given technique, it will hardly stop using it and substitute it with labor merely because of a change in relative prices (see Dosi and Nelson, 2010); (ii) in the presence of a theoretical isoquant that represents the negative relationship between capital and labor, a similarly negative relationship between capital and labor productivity would be also expected. However, contrary to what is theoretically predicted, Hildenbrand (1981), Dosi *et al.* (2016a), and Yu *et al.* (2015) empirically trace a zero or positive correlation between the two, providing evidence in favor of the absence of factor substitutability; (iii) the possibility of reswitching of the techniques due to multiple intersections of the isoquants (for a recent discussion on the Cambridge capital theory controversies, see Cohen and Harcourt, 2003) would allow, given the same relative prices, to have a coexistence of multiple capital/labor combinations; (iv) finally, labor mobility would imply workers move in favor of more attractive wage compensation. Even assuming that the production factors have a certain degree of substitutability,[7] it would be not easy to imagine that the direction of such substitutability goes from capital intensity to labor intensity in a given geographical area. The inherent concept of progress is, in fact, strongly related with the unilateral direction of technical change.

The previously described limitation also affects the compensation mechanism via new investment. Even under the effectiveness of Say's law, in which all the accumulated profits are reinvested, these investments would be directed to labor-saving machineries, breaking down the Keynesian channel that links more investment with more production, and thus more labor demand.

Furthermore, the new investment channel would work properly if it is limited to real investments. However, nowadays the rate of investment in the real economy appears lower than the rate of investment in purely financial activities. In particular, Lazonick (2011) describes the process of financialization occurring at the firm level where the "retain-reinvest" strategy have been translating into a "maximizing shareholder value" strategy in the last 20 years. This change of paradigm in investment activities is fairly evident when considering the massive increase of buybacks operations.

The income channel revealed to be effective mostly under a Fordist mode of production, where unionized labor was able to exert significant pressure on capitalists. Currently, the more fragmented labor force appears to be intrinsically less able to lay collective claims, partly as a result of an industrial relationship which is increasingly based on certain degrees of flexibility and individual bargaining.[8]

Finally, the new products channel looks rather subtle. Analyzing its history and diffusion, ICT has been one of the sectors with the highest rate of employment absorption in the last three decades,[9] responsible for significant product innovation (such as personal computers, mobile phones, and so forth). However, ICT also represents a process innovation for many related industries which use ICT.

One of the first attempts to empirically test the validity and effectiveness of *all* the compensation mechanisms is proposed by Vivarelli (1995). The author builds a theoretical macroeconomic model which combines both technological and market drivers. Focusing on the period between 1960 and 1988 in Italy and the USA, Vivarelli (1995) uses a three-stage least squares regression and shows that the most effective compensation mechanism in both countries is the one "via decrease in prices," while other mechanisms are less important. Nonetheless, this mechanism seems to *partially* compensate only the total contraction in labor demand. Moreover, in both countries the wage compensation mechanism does not effectively counterbalance unemployment. The U.S. economy in the period under analysis turns 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 do not counterbalance the labor-saving effect of prevailing process innovations.

In a subsequent work, Simonetti *et al.* (2000) compare American, Italian, French, and Japanese data between 1965 and 1993, confirming substantially analogous results. In their analysis, the authors emphasize that price and income seem the most effective compensation mechanisms in the economies under scrutiny, *irrespective* of country-specific institutional factors. Again, product innovation appears to be particularly effective in the USA.

Concluding, the complexity that involves the innovation-employment nexus is remarkably high. A comprehensive perspective seems therefore necessary to disentangle its nature. Non-Neoclassical approaches have historically proven to be more prone to recognize technology as a set of knowledge made by repeated acts, procedures, and routines. If this is the case, technology is tacit, rarely transferable and not easily substitutable. Removing the pillar of factors substitution and taking into account the local, cumulative, and nonreversible nature of technology, the extent to which a significant portion of compensation mechanisms apply seems to be more limited.

A general disequilibrium perspective (or a general equilibrium one) seems suitable to properly frame the effects of compensation mechanisms at different levels of aggregation: the success of one firm could be the failure of its competitors; the emergence of one sector could mark the end of another one.

3. From Firms to Sectors: The Role of Aggregation

This section critically reviews a considerable number of empirical contributions that analyze the links between innovative activity and employment at the firm level (Section 3.1) and the sectoral level (Section 3.3). An evolutionary *trait d'union* between the microlevel and the industry level is proposed in Section 3.2.

This section complements and significantly extends the scope of other reviews (such as Pianta, 2005 or Vivarelli, 2014, which mostly focus on evidence during the 1990s and early 2000s). Empirical evidence on how the relationship between innovation and employment changes over the business cycle is also presented. Differently from previous surveys, particular attention is devoted to a critical analysis of the different methodologies used and of their limitations. Substantial space is given to contributions that account for the effects of innovation over the entire employment growth distribution.

A particular effort throughout this essay is made in the attempt to reconcile results at different levels of investigation (firm-level vs. industry-level), especially when specific kinds of innovation are analyzed separately or when the empirical work goes beyond the analysis of conditional average effects. A synopsis is available in the Appendix, allowing a schematic visualization of the studies presented and including further details (see Tables A2, A3, and A4).

3.1 *Firm-Level Empirical Evidence*

The empirical debate on the innovation-employment nexus at firm level is long-standing. As emphasized by Vivarelli (2014), the microeconometric literature tends to support the existence of a positive relationship between innovation and employment, especially when R&D or product innovation are adopted as proxies of innovative activity and mostly when high-technology sectors are the center of the analyses.

A number of microeconometric studies use R&D intensity or patent counts as proxies of innovative activity. Such studies are not able to disentangle the effect of any of the compensation mechanisms presented above, but generally estimate correlations which are the net outcome (on employment) of the complex interaction of different forces. Other studies exploit the granularity of firm-level surveys (such as the Community Innovation Survey [CIS] in Europe) to separate the effects of innovation on employment into the components originating from product and process innovation, with different econometric techniques. Despite the limitations associated with such databases, this decomposition is able to catch peculiar effects on employment related to product innovation and to the compensation mechanism *via new products*.[10] Finally, other contributions pursue a structural modeling approach and aim to disentangle the extent to which other compensation mechanisms, such as the one *via decrease in prices*, affect the (otherwise net) effect of process innovation on employment.

A word of caution is necessary when interpreting findings of the firm-level analyses presented. The scope of this type of literature does not always directly nor automatically allow for the inference of industry-level dynamics. A positive effect of innovation on employment at the firm level may not be evidence of the fact that innovation induces a general increase in employment at the industry (or societal) level. As a matter of fact, business stealing and market expansion, competitive and selection dynamics, firm entry and exit, and the relocation of activities may induce completely different patterns at higher levels of aggregation. In addition, generally no conclusion can be drawn in regards to the effects on the composition of employment nor on the persistence of jobs created. Limitations associated with the different microeconometrics studies will be discussed in further detail.

3.1.1 *R&D, Patents, and Employment*

Traditional analyses of the impact of innovation on employment at the firm level use innovation inputs, such as R&D expenditures, or innovation outputs, such as patent data, as proxies for innovative activity. These two variables proxy innovation in different ways and suffer from different limitations and measurement issues.[11]

Given the substantial microeconomic heterogeneity, the effect of innovation inputs at the firm level might be characterized by nonconstant effects on employment. In this context, Bogliacino (2014) singles out two potential mechanisms that might induce nonlinearities in the firm-specific employment R&D elasticity: a scale effect according to which returns to scale may potentially be decreasing, and a size effect according to which economies of scale may potentially arise.[12]

Acknowledging the limitations of a single measure of innovation used in isolation, a few contributions also take advantage of composite innovation indicators, including a combination of the number of patents and R&D intensity, or innovation measures based on expert judgment.[13]

Many studies in the literature have suggested the existence of a positive relationship between innovation measures and employment or employment growth (see, among the others, Hall, 1987; Yang and Huang, 2005; Yasuda, 2005 for R&D; Van Reenen, 1997 and Greenhalgh *et al.*, 2001 for other composite measures), often taking a national perspective (see Nelson, 1993 for further discussion on National Innovation Systems) and acknowledging the persistent nature of firm-level employment.[14] Other works find less clear-cut evidence (see, for instance, Brouwer *et al.*, 1993; Klette and Førre, 1998 for R&D and Piva and Vivarelli, 2005 for other measures). Departing from previous surveys, we will concentrate our attention on the most recent empirical evidence.

In particular, studies that focus on different samples of firms, which have varying characteristics in terms of age, size, and sectors of activity are able to offer different perspectives on the microeconomic relationship between innovation and employment. In this respect, we will start by focusing on young firms, then shifting the attention to large ones. Regardless of firm characteristics, technology reveals to be an important factor that mediates the extent to which innovation influences employment dynamics. In this section, we will particularly emphasize the specificities associated with high-technology sectors.[15]

In this context, Stam and Wennberg (2009) use R&D behavior as a proxy of innovation to examine its impact on new product development, interfirm alliances and – relevant for our purpose – employment growth of newly born firms.

Stam and Wennberg (2009) exploit a comprehensive start-up database covering the Dutch economy biannually from 1994 to 2000. Their findings suggest that there is no significant relationship between R&D activities and employment growth, unless the attention is restricted to the fastest growing 10% of firms. They further suggest that R&D is positively associated with the growth of young high-technology firms, but not with low-tech start-ups' employment growth.

Shifting the attention to large firms, Bogliacino *et al.* (2012) assess how in-house corporate R&D affects employment on a panel of about 700 large European publicly traded companies, between 1990 and 2008.[16] They estimate a dynamic labor demand equation augmented with innovation variables by means of a Least Squares Dummy Variable Corrected (LSDVC) estimator.[17] Separately focusing on manufacturing (high-tech vs. low-tech) and services, their results highlight, once again, that the positive impact of R&D expenditures on employment is not significant in low-tech manufacturing sectors, but it is detectable in services and in high-tech manufacturing.

Restricting the focus to the high-tech manufacturing sector, where the positive role of innovative activities proved so far to be more intense, Coad and Rao (2011) combine patent and R&D data to investigate the relationship between innovation and employment growth in the USA.[18] They build a synthetic innovation indicator matching Compustat data with the NBER Innovation database, thereby limiting the possible drawbacks associated with the use of just one innovation measure individually (see Dosi, 1988). Combining OLS with Weighted Least Squares (WLS) and LSDVC methods, Coad and Rao (2011) argue that, in general, innovation is positively associated with subsequent employment growth in the U.S. high-tech manufacturing industry. Moreover, they present evidence in favor of a substantial variation in the regression coefficients over the conditional quantiles of the employment growth distribution. This confirms that innovation is significantly associated with employment growth for fast-growing high-tech firms, while it has almost no effect on high-tech firms experiencing rapidly negative employment growth.

Finally, Van Roy *et al.* (2015) further exploit patent data in a cross-country panel database of European patenting firms, covering the period of 2003–2012.[19] Differently from many contributions, this study includes patent quality information (based on forward citations) into the exploration of the innovation-employment nexus. Van Roy *et al.* (2015) estimate a labor demand equation augmented with (lagged) innovation by means of a system Generalized Method of Moments (GMM) approach. Their findings highlight a significantly positive effect of citation-based patenting activities on employment: doubling patenting increases employment by 5%. Furthermore, such positive effect remains significant only in high-tech manufacturing sectors, confirming the important role of technological characteristics in this framework.

The studies presented above tend to confirm a generally positive role of innovation on employment growth, at the firm level. This seems to hold particularly true for high-growth firms in high-tech sectors.[20] However, the scope of these studies does not allow a separate investigation of the effects of product and process innovation nor to test whether any of the above-described compensation mechanisms mediate the link between innovation and employment.

3.1.2 *More on Product and Process Innovation*

Over the last two decades, a number of empirical contributions have tried to unveil the individual effects of product and process innovations on firm-level employment. Most studies have found a positive link between product innovation and employment in businesses, especially when the products are not only new to the firm but also new to the entire market, while process innovation effects look more ambiguous (see, among the others, Pohlmeier and Entorf, 1990; Brouwer *et al.*, 1993; Smolny, 1998; Greenan and Guellec, 2000). Identifying the relationship between different types of innovation and employment is not an easy task and, as previously discussed, empirical estimates might reflect a combination of direct and indirect effects associated with innovative activity.

Within this stream of literature, a key contribution to the empirical and methodological debate is by Harrison *et al.* (2014).[21] The authors develop a framework in which they establish a firm-level theoretical relationship among employment growth, the dynamics of innovation output (product innovation), and productivity gains associated with process innovation within a production function setting. They then exploit data from the third wave of the CIS between 1998 and 2000 for Spain, Germany, the United Kingdom, and France to empirically test the model.

Harrison *et al.* (2014) argue that an overall positive relationship between innovation and employment holds at the firm level. Productivity improvements and process innovations tend to reduce employment, if output is held fixed.[22] However, increases in the output of older products seem to overcome this effect, increasing employment. The reduction of prices, associated with process innovation, appears to boost output expansion, though its magnitude is time-specific. This suggests that there is indirect evidence in favor of the existence of an effective *price compensation mechanism*. Furthermore, Harrison *et al.* (2014) confirm that the major source of firm-level positive employment changes is product innovation.

By developing a theoretical framework that is able to disentangle the effects associated with different types of innovation – accounting for a number of compensation mechanisms and estimating counterfactual industry-level effects, as will be discussed in the following section –, the model by Harrison *et al.* (2014) and its previous versions (see, for instance, Harrison *et al.*, 2008) have been further exploited in a number of recent empirical exercises focused on different countries.

In particular, Hall *et al.* (2009) do not find any evidence of displacement effects induced by process innovation in Italy, using data from the Mediocredito-Capitalia innovation survey from 1995 to 2003. They suggest that during the period examined employment growth sources come from product innovation and from old products' sales growth equally. They also highlight that the contribution of product innovation appears lower when compared to the countries analyzed by Harrison *et al.* (2008) and that innovative activity does not contribute to productivity growth in Italy during the sample period.[23] Benavente and Lauterbach (2008) analyze microdata from Chile between 1998 and 2001 and suggest that product innovation is positively and significantly linked with firm-level employment. However, they do not find any significant impact of process innovation on employment dynamics, after controlling for investment and sectoral patterns.

Crespi and Tacsir (2012) focus on the impact of product and process innovation on employment in Argentina, Chile, Costa Rica, and Uruguay exploiting microdata from innovation surveys across the late 1990s and 2000s. They confirm that product innovation is significantly linked with employment growth at the firm level, but observe limited labor displacement effects of process innovation in their Latin American sample.

Different from the studies associated with the model by Harrison *et al.* (2014), other authors have implemented empirical strategies less guided by structural models to assess the relationship between product and process innovation and employment (or employment growth).

In this respect, Lachenmaier and Rottmann (2011), using a long panel data set covering manufacturing firms in Germany for more than 20 years (1982–2002), adopt a dynamic (System-GMM) framework that takes into account not only unobserved heterogeneity, but also possible endogeneity of innovation and dynamic effects in innovative activities and in the employment adjustment process.

Lachenmaier and Rottmann (2011) suggest that there are significantly positive and robust effects of innovation on employment. In contrast with previous contributions, however, they find that the (net) effect of process innovation tends to be higher in magnitude with respect to the one of product innovation.[24] As emphasized by Vivarelli (2014, p. 15), "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." However, one should note that Lachenmaier and Rottmann (2011) have very few observations for process innovators who apply for patents.

The study by Lachenmaier and Rottmann (2011) suggests that the interaction of different indirect effects, differences in the quality of innovative activity and different degrees of the persistence of innovation might have a role in quantifying the magnitude of the firm-level relationship between innovation and employment. In this respect, Triguero *et al.* (2014) use Spanish panel data between 1990 and 2008 to further investigate whether firms show heterogeneous responses in employment growth depending on the degree of persistence of their different innovative activities, comparing Small and Medium Enterprises (SMEs) and larger firms. Similarly to Lachenmaier and Rottmann (2011), using a System-GMM estimator, they support the existence of a positive link between persistent process innovation activities and employment growth, with the magnitude of such an effect increasing with the time lag considered, especially for SMEs. Furthermore, no significant effect is found for persistence in product innovation on employment growth.[25]

Very few contributions analyze the effects of different types of innovation on employment growth, distinguishing between fast-growing and shrinking firms. Most recently, Herstad and Sandven (2015) link Norwegian CIS2008 data with the business register before and after the innovation survey. Combining different approaches, including ordered logit, they investigate the relationship between employment growth prior to innovative activity, innovation output, and growth after the innovation event.

Their results suggest a certain degree of autocorrelation in growth rates, and a correlation between ex ante growth and innovative activity, which further strengthen employment growth when both product and process innovations are introduced. Furthermore, Herstad and Sandven (2015), challenge common empirical findings by suggesting that process innovation is significantly associated with positive ex post employment growth, especially for firms at the top of the distribution.

In a similar vein but focusing exclusively on small and medium enterprises in Germany, Zimmermann (2009) estimates a quantile regression model in the context of a dynamic labor demand equation, investigating the effect of product and process innovation (occurring between time $t-2$ and $t-4$) on two-year average employment growth rates. The findings suggest that innovation (especially process innovation) has a positive impact on employment for both growing and shrinking SMEs in Germany, with stronger effects on high-growth SMEs mostly in the case of process innovation.

Despite strong theoretical reasons, which have been previously discussed, motivate the focus on different types of technological (product and process) innovations, an important role to shape firm-level employment dynamics is also played by nontechnological forms of knowledge and in particular by organizational innovation. Evangelista and Vezzani (2012) enrich previous analyses in this direction. Their estimates are based on a novel three-step approach: they first examine the impact of different innovative activities on sales growth (the so-called "innovation-induced growth process") which, they argue, is at the roots of any link between innovation and employment. Second, they investigate whether the innovation-induced growth process is related to positive employment effects. Finally, they assess the extent to which the positive employment effects are weakened in cases where firms' innovative activities consist of pure process or organizational innovation.[26] Evangelista and Vezzani (2012), exploiting cross-sectional CIS IV data for a selected number of European countries,[27] confirm the existence of an innovation-induced growth process, suggesting that all innovation strategies are linked, to some extent, to sales growth. They then provide evidence that innovation strategies combining product and process innovation present the strongest positive impact on employment in manufacturing and services, while process innovation does not show any direct negative effect, unless combined with organizational innovation in manufacturing.

To summarize, a number of studies presented in this section tested the compensation mechanism via new products explicitly, and have generally confirmed, with some relevant exceptions, the positive role of product innovation on employment. Process innovation has instead more ambiguous effects, suggesting a complex interaction of different forces in determining its net impact on employment dynamics. A few analyses, notably the one by Harrison *et al.* (2014), estimate a structural model in the attempt to separately identify the different effects associated with process innovation, in particular disentangling the price compensation mechanism and the extent to which it works in different countries. A limited number of studies examined the persistence of different types of innovation and the particular role of different innovative activities over the whole conditional employment growth distribution.

3.1.3 *Firm Innovation and Employment over the Business Cycle*

The effects of different types of innovative activities on employment dynamics is dependent on the particular phase of the economic cycle in which they occur. However, in our knowledge, limited empirical effort in recent years has focused on whether the role of innovative activities on employment dynamics is mitigated or exacerbated during different phases of the business cycle, at firm level.[28] A relevant exception can be found in the study by Peters *et al.* (2014).

Peters *et al.* (2014) use CIS data from 26 European countries – till the CIS 2010 wave – and the German contribution to the CIS, called the Mannheim Innovation Panel, to study the link between employment growth and innovation. In particular, they analyze how the effects of innovative activities on employment dynamics change during different phases of the business cycle.

They emphasize the complementarity of different types of innovative activities, focusing especially on the role of product and process innovation. Furthermore, they analyze the role of technological intensity, business cycle sensitivity, size, ownership structure, and location to mediate the employment effects of innovation over the business cycle.

In the framework of Harrison *et al.* (2014), Peters *et al.* (2014) provide evidence that product innovators have more substantial employment growth with respect to noninnovators, as employment generated by means of higher sales of novel products more than counterbalances the negative effects associated with decreasing sales of older ones. This pattern looks stronger in periods of economic upturn and boom, when product innovation is related to increasing sales, limited job destruction due to productivity effects, and to substitution of old products with new ones. Peters *et al.* (2014) argue that product innovation is highly important in times of recession, as it acts to preserve employment. In manufacturing, in fact, employment losses associated with product innovators are sensibly smaller during a recession than those of noninnovators. This effect seems even larger in services, where product innovators show a positive contribution to net employment growth. In addition, Peters *et al.* (2014) highlight that the effects of process and organizational innovation are more limited than those of product innovation in every phase of the business cycle. In particular, process and organizational innovation in manufacturing are linked to small labor-destroying productivity effects in upturn and downturn periods, while in booms and recession no relevant effect is identified. In services similar patterns hold, but no impact is found for process innovation. Finally, the authors point out the effect of 'labor hoarding" during recessions. In fact, the negative trend of productivity at the industry level positively affects employment growth in such phase of the cycle. This seems to suggest that firms do not always react instantaneously to sales reduction by laying off workers.

3.2 *From Firms to Sectors: Evidence on the effect of Selection on Employment Shares*

As already emphasized, different levels of aggregation crucially affect the way in which innovation influences employment and employment growth. Studies that focus on the relation between firm-level productivity and employment shares bridge between firm and industry analyses. In fact, productivity and process innovation are particularly linked via the labor-saving effect associated with this innovative activity. This strand of literature has not been analyzed in depth by previous reviews. Grounded in evolutionary theory, the dynamic relationship between productivity and shares of employment can be well represented by means of a replicator dynamics equation. On the empirical ground, a number of productivity decompositions that are able to catch the above-mentioned relation will be discussed.

Rooted in the Schumpeterian idea that more competitive firms are better able to gain market share, one of the most used analytical tools in evolutionary theory is the replicator dynamic equation:[29]

$$\Delta s_{i,t,t-1} = \Psi s_{i,t-1} \left(\frac{\Pi_{i,t}}{\overline{\Pi}_t} - 1 \right) \tag{1}$$

where

$$\overline{\Pi}_t = \sum_i \Pi_{i,t} s_{i,t-1} \tag{2}$$

Note that $s_{i,t}$ is the market share of firm i which changes as a function of the ratio of the firm's productivity (or competitiveness) to the weighted average of the industry ($\Pi_{i,t}/\overline{\Pi}_t$), and that the Ψ parameter indicates the intensity of the selection process. This equation aims to understand how the dynamic of market shares intertwines with firms' relative performance. As a matter of fact, it attempts to capture the *creative destruction* process at the core of the Schumpeterian view, which postulates that the best performers erode competitors' market shares until they exit the market. In the presence of an entry-exit process, the replicator dynamics equation will describe a pattern of endogenous sustained cyclical dynamics in market shares (see, for instance, Dosi *et al.*, 1995 for a theoretical example).

Is there any relationship between a firm's market performance and its ability to absorb the labor force? Furthermore, is it possible to trace a positive relationship between the change in market shares and the relative amount of the employed labor force? This would be equivalent to reformulate Equation (1) as

$$\Delta n_{i,t,t-1} = \Psi n_{i,t-1}\left(\frac{\Pi_{i,t}}{\overline{\Pi}_t} - 1\right) \tag{3}$$

where

$$\overline{\Pi}_t = \sum_i \Pi_{i,t} n_{i,t-1} \tag{4}$$

and $n_{i,t}$ is the employment share of firm i.

The closest econometric analysis that has been empirically undertaken to investigate the relation between job flows and productivity is the labor productivity decomposition originally proposed by Foster *et al.* (1998). Note that this type of productivity decomposition discards peculiarities associated with the entry-exit process. For a recent discussion on the pros and cons of alternative decomposition methods and a more in-depth analysis of the entry and exit dynamics, see Melitz and Polanec (2015). Let $\Pi_{i,t}$ be labor productivity at time t of firm i and let $AP_{j,t}$ represents the aggregate sector productivity of firm i in sector j defined as[30]

$$AP_{j,t} = \sum_{i\in j} \Pi_{i,t} s_{i,t} \tag{5}$$

The temporal variation of sectoral aggregate productivity can be rewritten as

$$\Delta AP_{j,t} = AP_{j,t} - AP_{j,t-1} = \sum_{i\in j}(\Delta\Pi_i s_{i,t-1}) + \sum_{i\in j}(\Delta s_i \Pi_{i,t-1}) + \sum_{i\in j}(\Delta\Pi_i \Delta s_i) \tag{6}$$

The first element represents the *within component* and aims to capture the evolution of productivity, holding market shares constant: in some ways, it grasps the learning process that occurs within the firm. The second element is the *between component*, which represents the market selection process, tracking the time evolution of market shares while holding productivity constant. The last term captures the *covariation* between the two effects.

This decomposition was originally proposed to analyze the reallocation process occurring at the market level. The *between effect* revealed to be much weaker than the other two components, different from what was predicted by the theory. Foster *et al.* (1998) examine U.S. data int the period of 1977–1987, using labor productivity and including the variation due to net entry, and find that the *within component* accounts for 45% instead the *between component* for −0.13% (this means that market shares move in antiefficient direction).

In a more recent paper, Bottazzi *et al.* (2010), also use labor productivity but exclude the net entry component and find for Italian (1991–2004) and French (1989–2004) data a *within component* of 152.73% and of 89.23% and a *between component* of −29.69% and a 11.79%, respectively, for Italy and France.

The *interaction term* captures our attention, as it is able to discern the relationship between productivity and employment on a medium level, in between the firm and the industry ones. Comparing the results for output and labor shares, the reported values of the interaction term reveal to be consistently negative when employment shares are used both for France and Italy (Bottazzi *et al.*, 2010) and for the USA (Foster *et al.*, 1998). Interestingly, in the USA the interaction terms changes from a positive to a negative effect when output shares are used in place of employment shares. This seems to suggest that, given the framework of these studies, productivity and employment shares inversely covariate, pointing to a labor-saving effect of technological progress.[31]

Baily *et al.* (1996) further analyze the relationship between *downsizing* in terms of employment and productivity growth. In particular, during the 1990s, a significant number of empirical literature associated the substantial increase in productivity growth (33% between 1977 and 1987) with the fall in employment (4.5%) that occurred over the same time span. However, when looking at the firm-level analysis as opposed to the aggregate, Baily *et al.* (1996) describe a much more complex process occurring in the U.S. market: (i) contrary to expectations, the mean business size only declined from 58 to 50 workers in that period; (ii) the typical plant was recorded to be very small; (iii) the typical worker used to be employed in a large plant; (iv) the overall contribution to aggregate productivity growth by plants that scaled-up was qualitatively similar to the one by downsizing plants; and (v) remarkable differences in terms of industry, size, ownership type, and region emerged between up-downsizing and productivity growth. Furthermore, the authors carry out an interesting exercise providing a comprehensive picture of the key operating driving forces, dividing total plants into four groups:[32]

1. Successful upsizers ($\Delta\Pi > 0 \quad \Delta s > 0$)]: Plants that experienced both an increase in labor productivity and in employment shares.
2. Successful downsizers ($\Delta\Pi > 0 \quad \Delta s < 0$)]: Plants that experienced an increase in labor productivity but a decrease in employment shares.
3. Unsuccessful downsizers ($\Delta\Pi < 0 \quad \Delta s < 0$)]: Plants that experienced both a decrease in labor productivity and in employment shares.
4. Unsuccesful upsizers ($\Delta\Pi < 0 \quad \Delta s > 0$)]: Plants that experienced a decrease in labor productivity and an increase in employment shares.

By performing the aggregate labor productivity decomposition, they found that the first two groups similarly account for the overall increase in manufacturing productivity (2.18 and 2.56 in absolute terms, respectively), compensating for the negative contribution of the other two groups. Given that the presence of the interaction effect in successful upsizers is positive and in the other, group 2, is instead negative, the within effect of successful downsizers is stronger than the one by successful upsizers, compensating for the negative cross term. The successful upsizers, whose interaction term is positive, may represent plants where the increase in productivity is accompanied by a growing demand which induces them to employ more labor force (firms absorbing labor due to the increase in demand). An alternative explanation is that their product demand reveals high price elasticity and almost perfectly competitive markets, such that productivity increases are transferred to final prices. On the other side, the successful downsizers, with a negative interaction term, face a constant or even declining demand, or conversely their products are characterized by a very rigid price elasticity.

Exploring a more recent data set with the aim of measuring cross-country differences in productivity growth, Bartelsman *et al.* (2009) confirm the negative sign of the interaction effect. However, when the sample is split into *low technology* and *medium-high technology* industries, the large negative cross-effect reveals to markedly characterize low technology industries. On the other hand, in medium-high technology industries such effect, tough still present, is smaller in magnitude.

On the same line, Bassanini (2010) performed a cross-country analysis and split the data into growing and declining firms. The findings support the presence of a negative and highly significant cross effect (conditioning on a number of firm characteristics), which holds for both subsets of businesses. Nonetheless, substituting multifactor productivity for labor productivity, the magnitude of the cross effect shrinks, becoming insignificant in almost all countries and slightly positive for growing firms in Italy, Poland, Sweden, and the United Kingdom.

In order to study the process of structural change, a similar labor productivity decomposition has been carried out at the sectoral level by Fagerberg (2000), who performs an extensive shift-share analysis across 24 industries in 39 market economies. This study reports a negative cross effect for almost all countries, with the notable exception of Ireland. The author clearly points out the displacing nature of technological innovation in the period under observation (1973–1990), where the employment creation capacity of the leading technology industries was clearly offset by the labor displacement effect induced by productivity growth. Conversely, the traditional sectors were the ones recording higher employment shares.

The contributions discussed in this section show, once again, that the relationship between process innovation, proxied here by productivity, and employment can take different forms when considering different levels of aggregation. In fact, in contrast with the firm-level empirical analyses, which tend to support the positive effect of product innovation but are rather inconclusive on the effect of process innovation, when productivity growth is explicitly considered as a proxy of technological progress, the labor-saving component seems to prevail. Another level of complexity is added when separately examining sector-specific innovation-employment trends, further investigating the extent to which the level of aggregation matters in explaining such a relationship. This will be the focus of the next section.

3.3 *Sectoral Empirical Evidence*

As previously emphasized, significant differences in the effects of innovative activities on employment dynamics can arise when comparing between the firm and the industry level of analysis. This section focuses on contributions that take, in different ways, a sectoral perspective.

In particular, some of the studies presented focus exclusively on the industry level of aggregation and try to disentangle the sectoral and technological specificities that drive differences in the innovation-employment nexus. Furthermore, other studies provide findings at the sectoral level juxtaposed on to a firm-level analysis. Those studies allow, at least to some extent, for a comparisons of divergent trends that occur at different level of aggregations. Recent analyses that take this approach are presented in the following subsection. A limited number of empirical applications investigate, instead, the extent to which sectoral peculiarities hold in different phases of the business cycle.

3.3.1 *Sectoral Specificities, Pavitt Classes, and Technological Regimes*

The analysis of sectoral trends in innovation and employment is long-standing, including contributions by Vivarelli *et al.* (1996), Sirilli and Evangelista (1998), and Antonucci and Pianta (2002). A number of recent studies conduct analyses exclusively at the industry level, focusing on the specificities of different technological regimes and sectoral systems of innovation (as conceptualized by Malerba, 2002; and Malerba and Orsenigo, 1993).

In this respect, Mastrostefano and Pianta (2009) investigate the effect of innovation on employment at the industry level by proposing a set of dynamic models in which employment changes are explained by changes in demand (in terms of value added), in wages, in the diffusion of innovation (proxied by the share of innovative firms) and in the economic impact (in terms of turnover share) of new products. They test different specifications of the model using CIS 2 and CIS 3 data from 10 manufacturing sectors in 10 European countries, between 1994 and 2001. The overall results suggest a positive contribution of demand growth, a negative role of wage changes (which disappears when longer lags are considered), limited effects from the general diffusion of innovation (probably associated with the dominance of process innovation behavior), and a positive role of the market impact of product innovation, only in high-innovation industries.

Bogliacino and Pianta (2010) further investigate the relationship between innovation and employment at the industry level in eight European countries, between 1994 and 2004 using CIS 2, 3, and 4 data. They analyze the effect of *cost competitiveness (CC)* (rooted in process innovation) and *technological competitiveness (TC)* (rooted in product innovation) on employment change (see also Pianta, 2001) differentiating manufacturing and services sectors according to a revised Pavitt taxonomy (see Pavitt, 1984; and Archibugi, 2001 for a review). They estimate an industry-level labor demand curve and include *CC*, *TC*, labor compensation, industrial dynamism, and productivity growth as controls. Their results suggest that *CC* a has negative impact on employment change while *TC* has a positive role. Furthermore, their findings highlight a negative wage effect and a positive dynamism effect. However, they argue that significant differences across the Pavitt classes confirm that innovative strategies vary across sectors and that peculiar mechanisms are at work in each class, as a result of the specific technological, demand, and labor market factors.[33]

Bogliacino and Vivarelli (2012) assess the job creation effects of R&D by combining a dynamic system GMM with an LSDVC analysis on a panel of 25 manufacturing and services sectors in 15 European countries, from 1996 to 2005. By estimating a labor-demand equation augmented with technology, they provide evidence of a positive employment effect of R&D expenditures, particularly concentrated in high-tech sectors.

Analyses presented in this section emphasized the role of sectoral specificities, in particular the sector's technological characteristics, the prevalence of product or process innovation, and the extent to which they mediate the innovation-employment relationship at the sectoral level. Further discussion on how sectoral specificities can be reconciled with the firm-level evidence is put forth in the following.

3.3.2 *Reconciling Firm-Level and Industry-Level Findings*

Studies discussed in the previous subsection focused exclusively on the sectoral level of analysis, identifying sector-specific trends associated with industry characteristics. Interestingly, a number of empirical investigations compared different levels of aggregations, shedding further light on the different dynamics peculiar to firms and sectors.

Using a sample of French firms between 1986 and 1990, Greenan and Guellec (2000) analyze job flow indicators in the spirit of Davis and Haltiwanger (1992) and estimate a structural model in which product innovation influences the demand function and process innovation changes the production function. They suggest that, at the firm-level, process innovation contributes more to employment growth (than product innovation). Furthermore, Greenan and Guellec (2000) calculate sector-level innovation indicators for a group of 37 sectors in the manufacturing industry, in order to investigate whether technical change contributes to within or between sector job reallocation. Their findings suggest that innovation is positively related to employment expansion in the sectors included in the analysis. Distinguishing among product and process innovation, they suggest that industry-level employment benefits instead more from product innovation. They also examine excess job reallocation patterns and highlight that product innovation contributes to within sectors job reallocation presumably by reallocating market shares between competing firms. They reconcile different effects at the firm and sector-level using a selection argument: process innovation generates job creation at the expense of competitors while product innovation has more moderate effects, and does not harm other firms in the sector.

Taking a similar perspective, Meriküll (2010) investigates the effect of product and process innovation on employment in Estonia, linking a panel from CIS 3 and 4 to the business register.[34] By means of dynamic panel estimations, the results suggest that product innovation has milder effects at the firm level while it has substantial positive effects at industry level, using an OLS estimation. Furthermore, Meriküll

(2010) points out that process innovation has a weak but significant positive effect at the firm level, in the medium and low tech subsample. However, when the analysis is carried out at the industry level, the observed effect tends to vanish. These findings, focused on a transition economy, generally confirm the analysis proposed by Greenan and Guellec (2000) in France.

Focusing instead on services, Evangelista and Savona (2003) investigate the employment impact of innovation, with data from the second wave of the Italian CIS (1993–1995). The authors estimate a binary logit model taking advantage of a qualitative variable in the survey that assesses the impact of innovation on employment (positive or negative-nil), differently from most contributions. The authors suggest that at the firm-level most innovative companies are more likely to exhibit a positive innovation-total employment association. In this case, innovative strategies are focused on the introduction of new services, the internal generation of knowledge, the acquisition of know-how or on marketing. Sectoral patterns and technological regimes have an important role in influencing the innovation-employment nexus. In fact, when shifting the focus of analysis to a more aggregate sectoral level, the positive link remains evident only for science and technology-based sectors (such as R&D, technical consultancy, computing and software), while the link is reversed in ICT-using (such as financial services or insurances) and technology-using (such as retail trade and transportation) industries. These findings reflect not only the idiosyncrasy of the Italian model of specialization in services,[35] but also confirm the differences associated with business stealing, market expansion, and selection at more aggregate levels.

Finally, the study previously presented by Harrison *et al.* (2014) further highlights the role of industry specificities in the four countries under analysis (France, Germany, the United Kingdom, and Spain). In particular, the authors report a lower rate of innovation in the service sector, with respect to the manufacturing sector. However, independently from the degree of innovativeness, the service sector exhibits higher average employment growth. In the context of this section, the structural model by Harrison *et al.* (2014) allows the authors to estimate counterfactual industry-specific market expansion and business stealing effects, attempting to link firm and sectoral levels of aggregation. The findings by Harrison *et al.* (2014) seem to be in favor of an overall positive effect of new products. According to their estimates, the maximum amount of business stealing in net employment growth of product innovators is about one-third, while the maximum amount that is reasonable to consider as market expansion and employment creation is slightly higher. Such results depend on assumptions concerning the specific demand-creation effect of the new products. One should note that the period examined by Harrison *et al.* (2014) generally corresponds to a positive phase of the business cycle (1998–2000).

Studies presented in this grouping have tried to adopt a comparative perspective, with a focus on similarities and differences between firm-level and industry-level findings. Selection dynamics seem to play an important role in this context, with business stealing effects associated mostly with process innovation. This suggests that industry-level employment might benefit more from product innovations in the sector (even though such an association might be less pronounced at the firm-level). In the following subsection, we will present a few sectoral analyses that investigate the extent to which the innovation-employment nexus changes along the economic cycle.

3.3.3 *Innovation, Employment, and the Business Cycle at Sectoral Level*

The role of the business cycle mediating the impact of innovation on employment dynamics at the firm-level has been presented in Section 3.1.3. At the microlevel, product innovation played an important role to preserve employment during times of boom, but also during recessions.

At the sectoral level, Lucchese and Pianta (2012) investigate how economic cycles affect the relationship between innovation and employment in manufacturing. The authors analyze whether upswings and downswings alter the possibility of taking advantage of technological opportunities and how the cycle influences employment dynamics, at the two-digit industry level. Their investigation examines 21 manufacturing sectors from 1995 to 2007 in Germany, France, Italy, the United Kingdom, the Netherlands, and Spain, combining CIS (2, 3, and 4) data together with the OECD Structural Analysis Database (STAN). They propose a model that uses proxies for TC and CC, level of exports, demand, and changes in labor compensation to explain employment changes at industry-country level, allowing their estimates to vary over the different phases of the business cycle (upswings and downswings).

Lucchese and Pianta (2012) suggest that innovation-based growth and employment dynamics operate in significantly different ways over the phases of the business cycle. More precisely, they show that in upswings job creation is enhanced by product innovation and exports, but reduced by a high wage growth. Conversely, during downswings the role of new products and the level of exports becomes insignificant, while job losses are associated with process innovation[36] and high wage dynamics. Lucchese and Pianta (2012) argue that during contractions, job losses are related to the restructuring of industries, especially where new labor-saving processes are more widespread. The job creating effect of product innovation vanishes and exports contract faster than jobs. Furthermore, the negative relation existing between employment change and wages looks stronger during downswings.

3.4 *Empirical Evidence: Challenges and Limitations*

A substantial number of recent empirical studies between firm and sectoral levels of aggregation have been reviewed in Sections 3.1, 3.2, and 3.3. A critical focus on the challenges and limitations of such analyses will be presented in this section, together with a few interesting avenues for further research.

First, innovative activity reveals itself to be an intrinsically complex phenomenon. Using different innovation proxies, ranging from patents to R&D expenditures or innovation dummies, is a clear challenge and substantially constrains the extent to which econometric analyses reflect empirical regularities. Many of the microeconometric studies presented rely on innovation survey data which provides a comprehensive outlook of firm's innovative activities, but also suffers from a considerable number of drawbacks. In fact, CIS-like data are typically self-reported, which might be particularly subject to measurement errors and anonymization challenges. Furthermore, they often do not include comprehensive information on firm characteristics, suffer from selection problems depending on specific sample representativeness, and generally focus only on continuing businesses (see Mairesse and Mohnen, 2010 for further discussion).

A number of microeconometric studies that investigate the firm-level impacts of innovation on employment exploit the model by Harrison *et al.* (2014). Such a methodology has clear advantages, as it focuses on different kinds of innovation and allows for the separate identification of the price compensation mechanisms and the estimation of the counterfactual industry-level effects. However, the identification and consistent estimation of the parameters of the employment growth equation proposed by Harrison *et al.* (2014) using CIS data involves a few critical assumptions, related to the use of a production function setting (see Atkinson and Stiglitz, 1969; Nelson and Winter, 1982; Dosi and Grazzi, 2006).

In particular, the coefficient estimates in the baseline firm-level specification refer to the difference between employment growth and old products' sales growth. Second, in order to deal with endogeneity issues associated with idiosyncratic productivity shocks, the model passes from a firm-specific to an industry-average specification to assess the implications of estimated effects on employment growth.

A more extensive and systematic effort should be devoted to linking firm and industry dynamics, with particular attention given to the selection process. Additional direct estimates should be undertaken on top of the indirect analyses of the cross-effect between productivity and employment shares. Moreover, empirically investigating the relevance of the replicator dynamics (Cantner and Krüger, 2008; Cantner *et al.*, 2012; Dosi *et al.*, 2015) could shed further light both on selection and learning processes occurring in markets. Linking innovation and employment dynamics with profitability seems to be another fruitful avenue for further research in this direction. Further analysis also would be crucial to understand the way in which aggregation influences the innovation-employment nexus.

Despite many empirical studies founded on the Schumpeterian distinction between product and process innovation, the components of these innovative activities are rarely discussed in depth. Reference definitions come from the OECD Oslo manual (OECD and Eurostat, 2005). Product innovation generally includes both new or significantly improved goods and services. Process innovation, on the other hand, encompasses new or significantly improved methods of production, delivery methods, changes in techniques, equipment or software, and can be apt to quality increase or cost decrease. Different building blocks of product and process innovation can have unusual effects on employment dynamics. For instance, the introduction of a new delivery system could require more workers, despite being a process innovation. Furthermore, the role of software and information systems can be ambiguous. It is widely discussed in the literature that debates on the skill-biased technical change hypothesis, see for instance Autor *et al.* (2003). This also seems a promising avenue for further research.

More systematic investigation on the role of product and process innovation, distinguishing between fast-growing and shrinking firms, would be interesting to further corroborate the results of the few studies presented, in light of the extent to which indirect effects might vary along the conditional employment growth distribution.

The number of firm-level studies that analyze the relationship between innovation persistence and employment growth is very limited. Further exploration on this topic would be an avenue for further research. In this framework, however, whenever time-invariant, individual fixed effects are included in econometric models, the identification of the impact of innovation on employment will be limited to those firms for which innovation is time-variant.

Some authors (explicitly or implicitly) claim that one level of aggregation is *better* than the other in order to assess the innovation-employment nexus. In our view, analyses performed at each level of aggregation, using different methodologies, offer a different piece of the puzzle. Firm-level analysis are not able to catch business-stealing and market-expansion effects, but provide a detailed overview of innovative activities at the microlevel. Sectoral analysis are able to grasp such dynamics but overlook intersectoral linkages and complementaries, which would be only caught at a macroeconomic level, which is left out of the scope of this survey.

4. Some Stylized Facts

This work has analyzed the relationship between innovation – in its declinations – and employment at different levels of aggregation. The manifold nature of technical change and the complexity of its interaction with employment dynamics have proven to characterize a large part of the evidence examined.

In this section, we will present a few stylized facts which have emerged from the most recent empirical evidence analyzed. Since the level of aggregation at which the relationship between innovation and employment is assessed has proven to be crucial, we will maintain this distinction in the presentation of the stylized facts.

SF1 Recent firm-level analyses suggest a generally positive relationship between innovation and employment growth. Innovation is proxied by R&D intensity most frequently or by patenting activity in a few studies. This seems particularly true when the attention is focused on high-growth, high-technology firms, especially in more innovative economies.

SF2 Different types of innovation have specific effects on firms' employment dynamics. In a general framework of complementarity,[37] the distinction between product and process innovation is confirmed to be theoretically fruitful.

SF3 Most empirical studies highlight the positive role of product innovation at the microeconomic level, notwithstanding the cannibalization of old products, which rarely appears to completely counterbalance the direct association with job creation. However, the effects of process innovation are more controversial. As a matter of fact, they are the outcome of interacting forces, notably the labor-saving direct effect, under fixed output, and the indirectly positive effect which is mainly associated with the price compensation mechanism. Recent evidence presented points to a generally nonnegative role of process innovation at the microeconomic level, suggesting that the direct effect does not always prevail on other counteracting forces. In this respect, it is worth recalling that few studies are able to account for competitive dynamics occurring at the market or sectoral level. A positive role of process innovation at the firm level might often hinder job displacement at industry level, to different degrees, when such effects are not estimated.

SF4 Comparing the magnitude of the effects across economies is not obvious and depends on country specificities, technological characteristics, differences in the competitive arena, and the extent to which different compensation mechanisms work.

SF5 A *trait d'union* between firm-level and industry-level studies is offered by those analyses that break down productivity and employment changes by means of shift-and-share decompositions. The majority of these studies tend to show a negative covariation between process innovations (proxied by productivity) and employment shares. Methodological caveats related to the specific decompositions used apply when analysing such results.

SF6 The sectoral analyses examined tend to highlight a positive effect of innovation on employment. However, sectoral specificities and technological characteristics, including the propensity to product or process innovation, prove to be important in driving such relationship, once again.

SF7 Some studies support the idea that the magnitude of the effect of process innovation on employment is significantly reduced when analyses are carried out at the sectoral level. This derives also from the role of competitive dynamics, such as business stealing, that become observable at this level of aggregation. One should note that these forces are counterbalanced by the diffusion of technologies in the industry, which can operate as sectoral analogous to the price compensation mechanism. On the other hand, product innovation generally is confirmed to be positively related to sectoral employment expansion and seems to be therefore a more important driving force at the industry level. Such a positive effect also benefits from market expansion, that is, the extent to which product innovators are able to attract new adopters. Different effects of product and process innovation at the firm and sectoral levels are schematically presented in Table A1 in the Appendix.

5. Concluding Remarks: We know (what) we don't know

The number, variety, and scope of the studies that have been reviewed reveal the recent developments in the conceptualization and empirical analysis of the effects of innovation and technical change on employment dynamics. A number of themes can be considered as developments on insights already presented in the contributions of classical economists including Marx and Ricardo and, after them, Schumpeter and Keynes. Other elements of investigation, and their declinations over the different levels of aggregation, have enriched the understanding of the innovation-employment nexus.

This work departs from previous analyses in different respects: [i] it significantly extends and discusses the most recent firm-level and industry-level contributions, focusing on the last decade since 2000, with particular attention given to the differences in methodologies and limitations; [ii] it emphasizes the impact of the aggregation level on the innovation-employment nexus; [iii] it investigates in detail the extent to which compensation mechanisms operate at the firm and the industry level; [iv] it discusses the firm-industry linkage, integrating results from shift and share decompositions of productivity on employment shares; [v] it examines the effect of business cycles and how they mediate the innovation-employment relationship.

A number of stylised facts have been presented in the previous section, disentangling the extent to which innovative activities are associated with employment or its growth at different levels of aggregation. Limitations associated with some of the empirical studies also have been discussed throughout this essay.

However, this analysis is far from exhaustive, despite being rich in a number of dimensions. Indeed, it does not cover all of the possible domains that are relevant to have a comprehensive view of the technology-employment nexus. In particular, a number of issues were omitted in the scope of the current survey.[38]

Limited attention has been devoted to the role of non-technological and organizational innovation and changes in working practices (e.g., lean production, team working, job rotation, total quality management), though these dimensions are important determinants of firm performance and exhibit clear complementarity with other innovative activities.

Part of this essay analyzed the association between productivity, as a proxy of process innovation, and employment, focusing especially on a number of studies based on shift-and-share decompositions. However, very limited attention has been devoted to the extent to which different types of innovation are related to productivity growth. A large body of literature focuses on such relationship (see for instance Hall, 2011 or Mohnen and Hall, 2013 for surveys and Crépon *et al.*, 1998 or Griffith *et al.*, 2006 for econometric models) which surely affects the innovation-employment nexus.

The role of international trade, exports and integration in the global value chain are likely to play a prominent role in influencing the extent to which innovation is associated with employment growth at different levels of aggregation (see for instance Dosi *et al.*, 1990). In addition, exporting firms might benefit from a learning effect (Baldwin and Gu, 2003). Furthermore, routinization and automation might well be linked particularly to the extent to which jobs are off-shorable, in the sense that more routinized activities might be among the ones more subject to be relocated or delocalized. This may have effects not only on the quality of employment but also on its quantity (see also Marcolin *et al.*, 2016). National patterns of specialization into different industries may also affect the innovation-employment relation at a more aggregate level, for instance in industries more prone to product or process innovation. All the above mentioned effects also might vary in developing versus developed economies.

Despite emphasizing the role of country specificities, we did not devote systematic attention to the analysis of the impacts of institutional factors on the innovation-employment relationship. The regulatory framework, especially in terms of employment protection legislation, minimum wage settings, access to finance and the strength of collective bargaining, was not taken into account in most studies presented but crucially affects the employment-innovation nexus (see, for instance, Andrews *et al.*, 2014 or Giuliodori and Stucchi, 2012) and the degree of persistence of the job created (Ciriaci *et al.*, 2016 provide indirect evidence on this issue using Spanish data). Furthermore, the features of national innovation systems (Freeman, 2002) were not discussed in detail, despite playing a key role among the country-specific determinants of the impact of innovation on employment.

A considerable body of related research, which was omitted in this analysis, examines the relation between digitalization and employment (see Sabadash, 2013 for a review; see also Brynjolfsson and McAfee, 2012 and Pantea *et al.*, 2014). In addition, few recent analyses look at the extent to which computerization, robotization and automation affect employment, and are particularly related to this study (see, for instance, Frey and Osborne, 2013; Brynjolfsson and McAfee, 2014; Graetz and Michaels, 2015; Arntz *et al.*, 2016; Berger and Frey, 2016). The role of innovation and automation on the quality of workers has been kept outside the scope of this chapter, thereby disregarding the presence of relevant compositional effects and the extent to which innovative activities influence the demand for skills. In particular, a body of literature debates the presence of routinized skill-biased technical change (see Autor, 2015) and whether a decrease in the demand for medium-skilled workers is associated with the so-called jobless recovery, as observed in the aftermath of the Great Recession (Jaimovich and Siu, 2012).

Extending the analysis towards a more comprehensive view, with particular reference to the firm-wage dynamics, the transformation of the shop floor, the effects of trade and international competition and the policy-institutional factors, would be a natural continuation of this work.

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Notes

1. Keynes popularized the concept of technological unemployment (see Keynes, 1931).
2. See chapter 12 of the *General Theory*.
3. Technoeconomic paradigms are intended as a macroconstellation of technological paradigms introduced in Dosi (1982).
4. For a distinction between the dynamics of productivity per worker and hourly productivity, see Sylos Labini (1984): whenever the latter is higher than the former this signals a reduction in the number of working hours. In principle, to measure the labor-displacement effect of innovation one should look at the reduction of working hours and not of labor force.
5. See also Harrison *et al.* (2014).
6. Note that the same mechanism is in place in the case of the introduction of new products confirming the absence of a clear-cut border between process and product innovation. As a matter of fact, looking at new machines in the machine-producing industry as a product, if complete cannibalization arises, such an industry would not benefit from any positive effect on employment. For a further discussion, see Katsoulacos (1984).
7. In this respect, Bessen (2015) argues how, in the estimation of an engineering production function of the U.S. cotton industry in the 19th century, a very low elasticity of substitution between looms and weavers was observed.
8. For a recent compendium on labor market structural reforms aimed at reducing workers bargaining power, see Adascalitei and Pignatti (2015).
9. For a projection on the U.S. Economy on the employment dynamics by major industry sector, see Henderson (2015).
10. Such surveys also allow the effects of organizational innovation to be captured. We do not particularly focus on effects related to this specific innovative activity in our work. See, for instance, Evangelista and Vezzani (2012) or Peters *et al.* (2014) for further discussion.
11. Patents are only able to measure the share of patented innovations, which could largely differ from the actual innovation output due to firm-specific innovation strategies or to patent requirements. R&D expenditures measure only one of the inputs of the innovation process and suffer from country-specific reporting requirements. See also Hagedoorn and Cloodt, 2003 for further discussion on the limitations of different innovation indicators.
12. According to the first argument, the gain from innovation may reach a saturation point, after which new innovation efforts do not translate into productivity growth, inducing a potential labor creation effect. According to the second argument, bigger firms may exploit gains from decreasing unit research costs, and as a result, enjoy cumulative productivity growth and labor displacement.
13. Measures based on experts' judgment include the SPRU database, which allows some of the drawbacks associated with traditional innovation measures to be overcome (see Van Reenen, 1997).
14. See the pioneering work by Nickell (1981).
15. Specificities associated with different sectors of the economies, in particular manufacturing versus services, are further discussed in Section 3.3 (see also Evangelista and Savona, 2003; Bogliacino *et al.*, 2013).

16. See also Aldieri *et al.* (2015) for a related analysis which also accounts for the role of outside R&D activity.
17. This methodology is more sophisticated than GMM in a dynamic panel setting with better performances when the sample is relatively small and unbalanced (see Bruno, 2005 for further details).
18. They focus on four 2-digit SIC codes sectors: industrial and commercial machinery and computer equipment; electronic and other electrical equipment and components, except computer equipment; transportation equipment; measuring, analyzing and controlling instruments; photographic, medical and optical goods; and watches and clocks.
19. The authors highlight that most patented innovations are products, as process innovation can be embedded into machines and can be kept secret more easily.
20. Most of these studies focus on developed countries. For a discussion of a newly industrialized country, see Mitra and Jha (2015).
21. The core of the model was already proposed by García *et al.* (1998), and further refined by Jaumandreu (2003) and Peters (2004).
22. Note that the negative effect of process innovation is significant in Germany and the United Kingdom, while it is generally insignificant in France and Spain.
23. Hall *et al.* (2009) use a slightly modified version of the model by Harrison *et al.* (2008) and rewrite their main employment equation in terms of labor productivity.
24. The same authors provide similar findings in a study based on the same data, using static panel methods (Lachenmaier and Rottmann, 2007).
25. More recently, Deschryvere (2014) conducted a similar study, but mostly focused on sales growth.
26. They identify the model by means of two simultaneous structural equations (an *economic performance* equation and an *employment* equation) and estimate it using Three-Stage Least Squares (3SLS).
27. Namely, Czech Republic, Spain, France, Italy, Portugal, and Slovenia.
28. Analyses at the sectoral level, such as Lucchese and Pianta (2012), are discussed in the following sections.
29. For a comprehensive discussion on replicator dynamics in economics, see Metcalfe (1998) and for a deep analysis on the ability of the latter to match stylized facts of industrial dynamics, see Dosi *et al.* (2016b).
30. Here, we use the notation proposed by Bottazzi *et al.* (2010).
31. Differences in the time spans and methodologies used in the two studies and peculiarities associated with each productivity decomposition, with particular emphasis on measurement error and the presence of the net entry component, must be adequately taken into account when analyzing these findings.
32. Though productivity might not always be a proxy for firms' success, this classification follows Baily *et al.* (1996).
33. See also Bogliacino *et al.* (2013) for further analysis in a similar spirit focused on business services.
34. Differently from Lachenmaier and Rottmann (2011), the author does not exploit an annual innovation survey.
35. In particular, the authors refer to the Italian despecialization in knowledge-intensive services.
36. Proxied by expenditure in innovative machines.
37. Note that descriptive statistics presented by Peters *et al.* (2014) and Harrison *et al.* (2014) suggest that the share of firms with both product and process innovation is higher than the shares of only-product or only-process innovators.
38. Of course this list should not be considered as exhaustive, despite our effort.

References

Adascalitei, D. and Pignatti, C. (2015) *Labour Market Reforms Since the Crisis: Drivers and Consequences*. Ginevra: International Labour Organization.

Aldieri, L., Garofalo, A. and Vinci, C. (2015) R&D spillovers and employment: a micro-econometric analysis. MPRA Paper No. 67269, MPRA, Munich.

Andrews, D., Criscuolo, C. and Menon, C. (2014) Do resources flow to patenting firms?: cross-country evidence from firm level data. OECD Economics Department Working Papers No. 1127, OECD Publishing.

Antonucci, T. and Pianta, M. (2002) Employment effects of product and process innovation in Europe. *International Review of Applied Economics* 16(3): 295–307.

Archibugi, D. (2001) Pavitt's taxonomy sixteen years on: a review article. *Economics of Innovation and New Technology* 10(5): 415–425.

Arntz, M., Gregory, T. and Zierahn, U. (2016) The risk of automation for jobs in OECD countries. OECD Social, Employment and Migration Working Papers No. 189, OECD Publishing, Paris.

Atkinson, A.B. and Stiglitz, J.E. (1969) A new view of technological change. *Economic Journal* 79(315): 573–578.

Autor, D. (2015) Why are there still so many jobs? The history and future of workplace automation. *Journal of Economic Perspectives* 29(3): 3–30.

Autor, D., Levy, F. and Murnane, R. (2003) The skill content of recent technological change: an empirical exploration. *Quarterly Journal of Economics* 118(4): 1279–1333.

Baily, M.N., Bartelsman, E.J. and Haltiwanger, J. (1996) Downsizing and productivity growth: myth or reality? *Small Business Economics* 8(4): 259–278.

Baldwin, J.R. and Gu, W. (2003) Export-market participation and productivity performance in Canadian manufacturing. *Canadian Journal of Economics/Revue canadienne d'économique* 36(3): 634–657.

Bartelsman, E., Haltiwanger, J. and Scarpetta, S. (2009) Measuring and analyzing cross-country differences in firm dynamics. In T. Dunne, J.B. Jensen and M.J. Roberts (eds.), *Producer Dynamics: New Evidence from Micro Data* (pp. 15–76). Chicago: University of Chicago Press.

Bassanini, A. (2010) Inside the perpetual-motion machine: cross-country comparable evidence on job and worker flows at the industry and firm level. *Industrial and Corporate Change* 19(6): 2097–2134.

Benavente, J.M. and Lauterbach, R. (2008) Technological innovation and employment: complements or substitutes? *European Journal of Development Research* 20(2): 318–329.

Berger, T. and Frey, C.B. (2016) Structural transformation in the OECD: Digitalisation, deindustrialisation and the future of work. OECD Social, Employment and Migration Working Papers 193, OECD Publishing, Paris.

Bessen, J. (2015) *Learning by Doing: The Real Connection between Innovation, Wages, and Wealth*. Yale: Yale University Press.

Bogliacino, F. (2014) Innovation and employment: a firm level analysis with European R&D scoreboard data. *Economia* 15(2): 141–154.

Bogliacino, F., Lucchese, M. and Pianta, M. (2013) Job creation in business services: innovation, demand, and polarisation. *Structural Change and Economic Dynamics* 25: 95–109.

Bogliacino, F. and Pianta, M. (2010) Innovation and employment: a reinvestigation using revised Pavitt classes. *Research Policy* 39(6): 799–809.

Bogliacino, F., Piva, M. and Vivarelli, M. (2012) R&D and employment: an application of the LSDVC estimator using European microdata. *Economics Letters* 116(1): 56–59.

Bogliacino, F. and Vivarelli, M. (2012) The job creation effect of R&D expenditures. *Australian Economic Papers* 51(2): 96–113.

Bottazzi, G., Dosi, G., Jacoby, N., Secchi, A. and Tamagni, F. (2010) Corporate performances and market selection: some comparative evidence. *Industrial and Corporate Change* 19(6): 1953–1996.

Boyer, R. (1988) Technical change and theory of "régulation". In G. Dosi, C. Freeman, R. Nelson, G. Silverberg and L. Soete (eds.), *Technical Change and Economic Theory*. London and New York: Pinter Publisher.

Brouwer, E., Kleinknecht, A. and Reijnen, J.O. (1993) Employment growth and innovation at the firm level. *Journal of Evolutionary Economics* 3(2): 153–159.

Bruno, G.S. (2005) Approximating the bias of the LSDV estimator for dynamic unbalanced panel data models. *Economics Letters* 87(3): 361–366.

Brynjolfsson, E. and McAfee, A. (2012) *Race against the Machine: How the Digital Revolution is Accelerating Innovation, Driving Productivity, and Irreversibly Transforming Employment and the Economy*. Lexington, MA: Digital Frontier Press.

Brynjolfsson, E. and McAfee, A. (2014) *The Second Machine Age: Work, Progress, and Prosperity in a Time of Brilliant Technologies*. New York: WW Norton & Company.

Cantner, U. and Krüger, J. (2008) Micro-heterogeneity and aggregate productivity development in the German manufacturing sector. *Journal of Evolutionary Economics* 18(2): 119–133.

Cantner, U., Krüger, J. and Söllner, R. (2012) Product quality, product price, and share dynamics in the German compact car market. *Industrial and Corporate Change* 21(5): 1085–1115.

Ciriaci, D., Moncada-Paternò-Castello, P. and Voigt, P. (2016) Innovation and job creation: a sustainable relation? *Eurasian Business Review* 6: 189–213.

Coad, A. and Rao, R. (2011) The firm-level employment effects of innovations in high-tech US manufacturing industries. *Journal of Evolutionary Economics* 21(2): 255–283.

Cohen, A.J. and Harcourt, G.C. (2003) Retrospectives: whatever happened to the Cambridge capital theory controversies? *Journal of Economic Perspectives* 17(1): 199–214.

Crépon, B., Duguet, E. and Mairesse, J. (1998) Research, innovation and productivity: an econometric analysis at the firm level. *Economics of Innovation and New Technology* 7(2): 115–158.

Crespi, G. and Tacsir, E. (2012) Effects of innovation on employment in Latin America. IDB Technical Note No. 496, Inter-American Development Bank.

Davis, S.J. and Haltiwanger, J. (1992) Gross job creation, gross job destruction, and employment reallocation. *Quarterly Journal of Economics* 107(3): 819–863.

Deschryvere, M. (2014) R&D, firm growth and the role of innovation persistence: an analysis of Finnish SMEs and large firms. *Small Business Economics* 43(4): 767–785.

Dosi, G. (1982) Technological paradigms and technological trajectories: a suggested interpretation of the determinants and directions of technical change. *Research Policy* 11(3): 147–162.

Dosi, G. (1984) Technology and conditions of macroeconomic development. In C. Freeman (ed.), *Design, Innovation and Long Cycles in Economic Development* (pp. 99–125). London: Design Research Publications.

Dosi, G. (1988) Sources, procedures, and microeconomic effects of innovation. *Journal of Economic Literature* 26(3): 1120–1171.

Dosi, G. and Grazzi, M. (2006) Technologies as problem-solving procedures and technologies as input–output relations: some perspectives on the theory of production. *Industrial and Corporate Change* 15(1): 173–202.

Dosi, G. and Nelson, R.R. (2010) Technical change and industrial dynamics as evolutionary processes. In B.H. Hall and N. Rosenberg (eds.), *Handbook of the Economics of Innovation*, Vol. 1 (pp. 51–127). Amsterdam: North-Holland.

Dosi, G., Freeman, C., Nelson, R., Silverberg, G. and Soete, L. (1988) *Technical Change and Economic Theory*. London and New York: Pinter Publisher.

Dosi, G., Pavitt, K. and Soete, L. (1990) *The Economics of Technical Change and International Trade*. New York: New York University Press.

Dosi, G., Marsili, O., Orsenigo, L. and Salvatore, R. (1995) Learning, market selection and the evolution of industrial structures. *Small Business Economics* 7(6): 411–436.

Dosi, G., Moschella, D., Pugliese, E. and Tamagni, F. (2015) Productivity, market selection, and corporate growth: comparative evidence across US and Europe. *Small Business Economics* 45(3): 1–30.

Dosi, G., Grazzi, M., Marengo, L. and Settepanella, S. (2016a) Production theory: accounting for firm heterogeneity and technical change. *Journal of Industrial Economics* (forthcoming).

Dosi, G., Pereira, M. and Virgillito, M. (2016b) The footprint of evolutionary processes of learning and selection upon the statistical properties of industrial dynamics. *Industrial and Corporate Change* (forthcoming).

Evangelista, R. and Savona, M. (2003) Innovation, employment and skills in services. Firm and sectoral evidence. *Structural Change and Economic Dynamics* 14(4): 449–474.

Evangelista, R. and Vezzani, A. (2012) The impact of technological and organizational innovations on employment in European firms. *Industrial and Corporate Change* 21(4): 871–899.

Fagerberg, J. (2000) Technological progress, structural change and productivity growth: a comparative study. *Structural Change and Economic Dynamics* 11(4): 393–411.

Foster, L., Haltiwanger, J. and Krizan, C. (1998) Aggregate productivity growth: lessons from microeconomic evidence. In C.R. Hulten, E.R. Dean and M.J. Harper (eds.), *New Developments in Productivity Analysis*. Chicago: University of Chicago Press.

Freeman, C. (2002) Continental, national and sub-national innovation systems – complementarity and economic growth. *Research Policy* 31(2): 191–211.

Freeman, C. and Perez, C. (1988) Structural crises of adjustment: business cycles and investment behaviour. In G. Dosi, C. Freeman, R. Nelson, G. Silverberg and L. Soete (eds.), *Technical Change and Economic Theory*. London and New York: Pinter Publisher.

Freeman, C. and Soete, L. (1994) *Work for All or Mass Unemployment? Computerised Technical Change into the 21st Century*. London and New York: Pinter Publisher.

Freeman, C., Clark, J. and Soete, L. (1982) *Unemployment and Technical Innovation*. London and New York: Pinter Publisher.

Frey, C.B. and Osborne, M.A. (2013) The future of employment: how susceptible are jobs to computerisation? Oxford University Working Paper September 17, Oxford University.

García, A., Jaumandreu, J. and Rodríguez, C. (1998) Innovation and jobs at the firm level. Documento de Trabajo No. 9810, Programa de Investigaciones Economicas.

Giuliodori, D. and Stucchi, R. (2012) Innovation and job creation in a dual labor market: evidence from Spain. *Economics of Innovation and New Technology* 21(8): 801–813.

Graetz, G. and Michaels, G. (2015) Robots at work. CEPR Discussion Paper No. DP10477, Center for Economic Policy Research.

Greenan, N. and Guellec, D. (2000) Technological innovation and employment reallocation. *Labour* 14(4): 547–590.

Greenhalgh, C., Longland, M. and Bosworth, D. (2001) Technological activity and employment in a panel of UK firms. *Scottish Journal of Political Economy* 48(3): 260–282.

Griffith, R., Huergo, E., Mairesse, J. and Peters, B. (2006) Innovation and productivity across four European countries. *Oxford Review of Economic Policy* 22(4): 483–498.

Hagedoorn, J. and Cloodt, M. (2003) Measuring innovative performance: is there an advantage in using multiple indicators? *Research Policy* 32(8): 1365–1379.

Hall, B.H. (1987) The relationship between firm size and firm growth in the US manufacturing sector. *Journal of Industrial Economics* 35(4): 583–606.

Hall, B.H. (2011) Innovation and productivity. NBER Working Papers No. 17178, National Bureau of Economic Research.

Hall, B.H., Lotti, F. and Mairesse, J. (2009) Innovation and productivity in SMEs: empirical evidence for Italy. *Small Business Economics* 33(1): 13–33.

Harrison, R., Jaumandreu, J., Mairesse, J. and Peters, B. (2008) Does innovation stimulate employment? A firm-level analysis using comparable micro-data from four European countries. NBER Working Paper No. 14216, National Bureau of Economic Research.

Harrison, R., Jaumandreu, J., Mairesse, J. and Peters, B. (2014) Does innovation stimulate employment? A firm-level analysis using comparable micro-data from four European countries. *International Journal of Industrial Organization* 35: 29–43.

Henderson, R. (2015) Industry employment and output projections to 2024. Monthly labor review, U.S. Bureau of Labor Statistics.

Herstad, S.J. and Sandven, T. (2015) Innovation and corporate employment growth revisited. Papers in Innovation Studies No. 2015/3, Lund University, CIRCLE-Center for Innovation, Research and Competences in the Learning Economy.

Hildenbrand, W. (1981) Short-run production functions based on microdata. *Econometrica* 49(5): 1095–1125.

Jaimovich, N. and Siu, H.E. (2012) The trend is the cycle: job polarization and jobless recoveries. NBER Working Paper No. 18334, National Bureau of Economic Research.

Jaumandreu, J. (2003) Does innovation spur employment? A firm-level analysis using Spanish CIS data. Mimeo.

Katsoulacos, Y. (1984) Product innovation and employment. *European Economic Review* 26(1): 83–108.

Keynes, J.M. (1931) Economic possibilities for our grandchildren. In *Essays in Persuasion*, (pp. 358–373). London: Macmillan & Co.

Keynes, J.M. (1963) A self-adjusting economic system. *Nebraska Journal of Economics and Business* 2(2): 11–15.

Klette, J. and Førre, S.E. (1998) Innovation and job creation in a small open economy – evidence from Norwegian manufacturing plants 1982–92. *Economics of Innovation and New Technology* 5(2–4): 247–272.

Kondratieff, N. and Stolper, W. (1935) The long waves in economic life. *Review of Economics and Statistics* 17(6): 105–115.

Lachenmaier, S. and Rottmann, H. (2007) Employment effects of innovation at the firm level. *Jahrbücher für Nationalökonomie und Statistik* 227(3): 254–272.

Lachenmaier, S. and Rottmann, H. (2011) Effects of innovation on employment: a dynamic panel analysis. *International Journal of Industrial Organization* 29(2): 210–220.

Lazonick, W. (2011) Reforming the financialized business corporation. Mimeo.

Lucchese, M. and Pianta, M. (2012) Innovation and employment in economic cycles. *Comparative Economic Studies* 54(2): 341–359.

Mairesse, J. and Mohnen, P. (2010) Using innovation surveys for econometric analysis. In B.H. Hall and N. Rosenberg (eds.), *Handbook of the Economics of Innovation*, Vol. 2 (pp. 1129–1155). Amsterdam: North-Holland.

Malerba, F. (2002) Sectoral systems of innovation and production. *Research Policy* 31(2): 247–264.

Malerba, F. and Orsenigo, L. (1993) Technological regimes and firm behavior. *Industrial and Corporate Change* 2(1): 45–71.

Marcolin, L., Miroudot, S. and Squicciarini, M. (2016) Routine jobs, employment and technological innovation in global value chains. OECD Science, Technology and Industry Working Papers No. 2016/01, OECD Publishing.

Mastrostefano, V. and Pianta, M. (2009) Technology and jobs. *Economics of Innovation and New Technology* 18(8): 729–741.

Melitz, M.J. and Polanec, S. (2015) Dynamic Olley-Pakes productivity decomposition with entry and exit. *RAND Journal of Economics* 46(2): 362–375.

Meriküll, J. (2010) The impact of innovation on employment: firm-and industry-level evidence from a catching-up economy. *Eastern European Economics* 48(2): 25–38.

Metcalfe, J.S. (1998) *Evolutionary Economics and Creative Destruction*. New York: Routledge.

Mitra, A. and Jha, A.K. (2015) Innovation and employment: a firm level study of Indian industries. *Eurasian Business Review* 5(1): 45–71.

Mohnen, P. and Hall, B.H. (2013) Innovation and productivity: an update. *Eurasian Business Review* 3(1): 47–65.

Nelson, R. (1993) *National Innovation Systems: A Comparative Analysis*. Oxford and New York: Oxford University Press.

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

Nickell, S. (1981) Biases in dynamic models with fixed effects. *Econometrica* 49(6): 1417–1426.

OECD and Eurostat (2005) *Oslo Manual: Guidelines for Collecting and Interpreting Innovation Data*, 3rd edn. The Measurement of Scientific and Technological Activities, OECD Publishing.

Pantea, S., Biagi, F. and Sabadash, A. (2014) Are ICT displacing workers? Evidence from seven European countries. Digital Economy Working Paper 2014/07, Institute for Prospective and Technological Studies, Joint Research Centre.

Pavitt, K. (1984) Sectoral patterns of technical change: towards a taxonomy and a theory. *Research Policy* 13(6): 343–373.

Peters, B. (2004) Employment effects of different innovation activities: microeconometric evidence. ZEW Discussion Papers No. 04-73, ZEW - Center for European Economic Research.

Peters, B., Dachs, B., Dünser, M., Hud, M., Köhler, C. and Rammer, C. (2014) *Firm Growth, Innovation and the Business Cycle*. Number No. 110577. Mannheim: ZEW - Center for European Economic Research.

Pianta, M. (2001) Innovation, demand and employment. In P. Petit and L. Soete (eds.), *Technology and the Future of European Employment* (pp. 142–165). Cheltenham: Edward Elgar Publishing.

Pianta, M. (2005) Innovation and employment. In D.M.J. Fagerberg and R. Nelson (eds.), *The Oxford Handbook of Innovation* (pp. 568–598). Oxford: Oxford University Press.

Piva, M. and Vivarelli, M. (2005) Innovation and employment: evidence from Italian microdata. *Journal of Economics* 86(1): 65–83.

Pohlmeier, W. and Entorf, H. (1990) Employment, innovation and export activity: evidence from firm-level data. In J. Florens, M. Ivaldi, J. Laffont and F. Laisney (eds.), *Microeconometrics: Surveys and Applications*, (pp. 394–415). London: Basil Blackwell.

Ricardo, D. (1817) *On the Principles of Political Economy and Taxation*. London: John Murray.

Sabadash, A. (2013) ICT-induced technological progress and employment: a happy marriage or a dangerous liaison? a literature review. JRC Technical Reports 2013/07, Institute for Prospective and Technological Studies, Joint Research Centre.

Simonetti, R., Taylor, K. and Vivarelli, M. (2000) Modelling the employment impact of innovation. In M. Vivarelli and M. Pianta (eds.), *The Employment Impact of Innovation: Evidence and Policy* (pp. 26–43). London: Routledge.

Sirilli, G. and Evangelista, R. (1998) Technological innovation in services and manufacturing: results from Italian surveys. *Research Policy* 27(9): 881–899.

Smolny, W. (1998) Innovations, prices and employment: a theoretical model and an empirical application for West German manufacturing firms. *Journal of Industrial Economics* 46(3): 359–381.

Spiezia, V. and Vivarelli, M. (2002) Innovation and employment: a critical survey. In N. Greenan, L'Horty, Y. and J. Mairesse (eds.), *Productivity, Inequality and the Digital Economy: A Transatlantic Perspective* (pp. 101–131). Cambridge, MA: MIT Press.

Stam, E. and Wennberg, K. (2009) The roles of R&D in new firm growth. *Small Business Economics* 33(1): 77–89.

Sylos Labini, P. (1984) *Le forze dello sviluppo e del declino*. Roma-Bari: Laterza.

Triguero, A., Corcoles, D. and Cuerva, M.C. (2014) Persistence of innovation and firms growth: evidence from a panel of SME and large Spanish manufacturing firms. *Small Business Economics* 43(4): 787–804.

Van Reenen, J. (1997) Employment and technological innovation: evidence from UK manufacturing firms. *Journal of Labor Economics* 15(2): 255–284.

Van Roy, V., Vertesy, D. and Vivarelli, M. (2015) Innovation and employment in patenting firms: empirical evidence from Europe. IZA Discussion Paper No. 9147, Institute for the Study of Labor (IZA).

Vivarelli, M. (1995) *The Economics of Technology and Employment: Theory and Empirical Evidence*. London: Edward Elgar Publishing.

Vivarelli, M. (2013) Technology, employment and skills: an interpretative framework. *Eurasian Business Review* 3(1): 66–89.

Vivarelli, M. (2014) Innovation, employment and skills in advanced and developing countries: a survey of economic literature. *Journal of Economic Issues* 48(1): 123–154.

Vivarelli, M., Evangelista, R. and Pianta, M. (1996) Innovation and employment in Italian manufacturing industry. *Research Policy* 25(7): 1013–1026.

Yang, C.H. and Huang, C.H. (2005) R&D, size and firm growth in Taiwan's electronics industry. *Small Business Economics* 25(5): 477–487.

Yasuda, T. (2005) Firm growth, size, age and behavior in Japanese manufacturing. *Small Business Economics* 24(1): 1–15.

Yu, X., Dosi, G., Lei, J. and Nuvolari, A. (2015) Institutional change and productivity growth in China's manufacturing: the microeconomics of knowledge accumulation and creative 'restructuring'. *Industrial and Corporate Change* 24(3): 565–602.

Zimmermann, V. (2009) The impact of innovation on employment in small and medium enterprises with different growth rates. *Jahrbücher für Nationalökonomie und Statistik* 229(2/3): 313–326.

Appendix

Table A1. Effects of Product and Process Innovation at Firm and Sector Level

	Product Innovation	Process Innovation
Firm Level	Positive (+) Notwithstanding Cannibalization ⇓ Products Compensation Mechanism	Directly Negative (−) (Under fixed output) Indirectly Positive (+) (Under output expansion) ⇓ Price Compensation Mechanism
Industry Level	Business Stealing ⇒ No effect (0) Market expansion ⇒ Positive (+)	Negative (−) (also for Business Stealing) ⇓ Sectoral Shift-Structural Change Indirectly Positive (+) ⇓ Technology Diffusion

Table A2. Synoptic Table: Firm-Level Studies

Firm level Study	Dependent variable & Proxy for technology	Methodology	Data	Country (Time period)	Results
Stam and Wennberg (2009)	Employment growth & R&D	OLS	Start-up database	The Netherlands (1994–2000)	No average effect between R&D and employment growth. (+) Effect on top 10% and high tech
Bogliacino *et al.* (2012)	Employment level & R&D	LSDVC	700 Large firms	Europe (1990–2008)	(+) Impact of R&D on employment in services and high-tech manufacturing
Coad and Rao (2011)	Employment growth & R&D and patents	OLS, WLS LSDVC	Compustat & NBER Innovation	USA (1963–1997)	(+) Effects on employment for fast-growing high-tech firms
Van Roy *et al.* (2015)	Employment growth & patent quality information (forward citation)	System GMM	Panel dataset (patenting)	Europe (2003–2012)	(+) Effect of patenting activities on employment but valid only for high-tech manufacturing sectors
Harrison *et al.* (2014)	Employment growth & Product and Process innov. (old and new products)	Structural model, OLS and IV	CIS 3	Spain, Germany, U.K., and France (1998–2000)	(−) Effect of process innovation under fixed output. (+) Effect of product innovation
Hall *et al.* (2009)	Employment growth & Product and Process innovation	Structural model, OLS and IV	Mediocredito-Capitalia	Italy (1995–2003)	No displacement effect of process innovation. (+) Effect of new and old products

(*Continued*)

Table A2. *Continued*

Firm level Study	Dependent variable & Proxy for technology	Methodology	Data	Country (Time period)	Results
Benavente and Lauterbach (2008)	Employment growth & Product and Process innovation	Structural model OLS and IV	Microdata (surveys)	Chile (1998–2001)	(+) Effect of product innovation. No effect of process
Crespi and Tacsir (2012)	Employment growth & Product and Process innovation	Structural model OLS and IV	Firm level data Innovation Survey	Argentina, Chile, Costa Rica, and Uruguay (late 1990s–2000s)	(+) Effect of product, no effect of process innovation
Lachenmaier and Rottmann (2011)	Employment growth & Product and Process innovation	System GMM	Ifo Innovation Survey (panel)	Germany (1982–2002)	(+) Effect of process > than product innovation
Triguero *et al.* (2014)	Employment growth & Persistent innovation	System GMM	ESEE (panel)	Spain (1990–2008)	(+) Link between persistent process innovation and employment growth, no role of persistent product innovation
Herstad *et al.* (2015)	Employment growth & different types of innovative activities	Ordered logit (and others)	CIS2008 linked with BR	Norway (2004–2010)	(+) Correlation between ex ante growth and innovative activity (+) Effect of process innovation on ex post employment growth, for firms in the top of the distribution
Zimmermann (2009)	Employment growth & Product and process innovation	Quantile Regression	Panel of SMEs	Germany (2003–2006)	(+) Effect of process innovation on employment for both growing and shrinking SMEs. Stronger effects on high-growth SMEs

(*Continued*)

Table A2. *Continued*

Firm level Study	Dependent variable & Proxy for technology	Methodology	Data	Country (Time period)	Results
Evangelista and Vezzani (2012)	Employment growth & Product, process organizational innovation	3SLS	CIS 4	Six European countries (2002–2004)	(+) Effect of product and process innovation on employment in manufacturing and services. (−) Effect of process innovation when combined with organizational innovation
Peters *et al.* (2014)	Employment growth & Product and process innovation	Structural model OLS and IV	CIS 3-4-2006 2008-2010	26 European Countries (1998–2010)	(+) employment growth for product innovators, particularly during booms. Employment-preserving effect of product innovation during downturns. Limited role of process innovation

Table A3. Synoptic Table: Cross Effect in the Shift-and-Share Decomposition

Study	Dependent variable	Shift-and-share methodology	Data	Country (Time period)	Cross effect
Foster *et al.* (1998)	Labor productivity	Net entry component Employment weight Output weight	Establishment level	USA (1979–1989)	(−) Employment weight (+) Output weight
Bottazzi *et al.* (2010)	Labor productivity	No net entry component Employment weight Output weight	Firm level	Italy/(1991–2004) France/(1989–2004)	(−) Employment weight (−) Output weight
Baily *et al.* (1996)	Labor productivity	No net entry component Employment weight	Establishment level	USA (1979–1989)	(−) for successful downsizers (+) for successful upsizers
Bartelsman *et al.* (2009)	Labor productivity	Net entry component Employment weight	Microaggregated data	14 countries Different time spans	Strongly (−) for low-tech ind. Mildly (−) for medium/hight-tech
Bassanini (2010)	Labor productivity Multi-factor productivity	Employment weight (conditioning on firm characteristics)	Firm level	10 countries Different time spans	(−) for all firms (−) or null for shrinking (+) for growing firms
Fagerberg (2000)	Labor productivity	No net entry component Employment weight	UNIDO-Sectoral level	39 countries (1977–1990)	(−) for most countries

Table A4. Synoptic Table: Industry-Level Studies

Sectoral-level Study	Dependent variable & Analysis	Methodology	Data	Country (Time period)	Results
Mastrostefano and Pianta (2009)	Employment growth & Demand, wages, diffusion of technology, product innovation	GLS fixed effects OLS	CIS 2-3 OECD STAN (manufacturing)	10 European countries (1994–2001)	(+) Effect of demand growth, (−) role of wage changes, low effects of diffusion of innovation, (+) role of product innovation, only in high-innovation industries
Bogliacino and Pianta (2010)	Employment growth & Cost Competitiveness (CC) Technological competitiveness (TC)	WLS	CIS 2-3-4 KLEMS OECD STAN	8 European countries (1994–2004)	CC has a (−) impact on employment changes. TC has (+) effects
Bogliacino and Vivarelli (2012)	Employment growth & R & D expenditures	System GMM and LSDVC	OECD STAN and OECD ANBERD	15 European countries (1996–2005)	(+) effect of R& D expenditures particularly in high-tech sectors
Greenan and Guellec (2000)	Jobs flows – employment growth & Product and process innovation	Structural model OLS, IV	EAE (innovation survey) and SUSE (INSEE)	France (1986–1990)	At firm-level, (+) effect of process innovation > than product on employment growth. Industry-level employment benefits more from product innovation
Merikull (2010)	Job flows – employment growth & Product and process innovation	OLS, FE, GMM	CIS 3-4 Business Register	Estonia (1994–2006)	Product innovation has mild effects at firm-level, (+) at industry. Process innovation weakly (+) at firm-level, (-) at industry. Limited net effects

(*Continued*)

Table A4. *Continued*

Sectoral-level Study	Dependent variable & Analysis	Methodology	Data	Country (Time period)	Results
Evangelista and Savona (2003)	Employment (qualitative var.) & different innovation variables	Binary logit	CIS 2	Italy (1993–1995)	At firm-level, new services have a (+) impact on employment. At sectoral level, the (+) impact is only in science and technology based sectors and (−) in ICT and technology using industries
Lucchese and Pianta (2012)	Employment growth & Product and process innovation (up-down-swings)	WLS	CIS 2-3-4 OECD STAN (manufacturing)	Germany, France, Italy, and U.K. (1995–2007)	In upswings (+) effect of product innovation; in downswings (−) effect of process innovation