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Abstract

The aim of this paper is twofold. On the one hand, the economic insights about the employment impact of technological change are disentangled starting from the classical economists to nowadays theoretical and empirical analyses. On the other hand, an empirical test is provided; in particular, longitudinal data - covering manufacturing and service sectors over the 1998-2011 period for 11 European countries - are used to run GMM-SYS and LSDVC estimates. Two are the main results: 1) a significant labour-friendly impact of R&D expenditures (mainly related to product innovation) is found; yet, this positive employment effect appears to be entirely due to the medium-and high-tech sectors, while no effect can be detected in the low-tech industries; 2) capital formation is found to be negatively related to employment; this outcome points to a possible labour-saving effect due to the embodied technological change incorporated in gross investment (mainly related to process innovation).

Key words: technological change; employment; sectoral analysis; EU
JEL codes: O33

1. *Introduction*

"....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, 1951, vol 1, p. 392; third edition, 1821)

"The accumulation of capital, though originally appearing as its quantitative extension only, is effected, as we have seen, under a progressive qualitative change in its composition, under a constant increase of its constant, at the expense of its variable constituent."
(Marx, 1961, vol. 1; p. 628; first ed. 1867).

David Ricardo's and Karl Marx's concern about "technological unemployment" appears as a common trait of capitalist societies over time.

Moving to the present age, in the past decades the emergence and widespread diffusion of a "new technological paradigm" (Dosi, 1982 and 1988) based on ICT and automation has led to a dramatic social impact within the employment structure in all the industrialized economies.

More recently, the arrival of 3D printing, self-driving autonomous cars (Tesla, Apple, Google), agricultural robots and so on so forth has raised again a widespread fear of an upcoming massive technological unemployment. Moreover, not only agricultural and manufacturing employment appears at risk, but employees in services - including cognitive skills - are no longer protected: see for instance how IBM Watson may displace the majority of legal advices, how Uber (just a software tool) is fully crowding out taxi companies and how Airbnb is becoming the biggest "hotel company" in the world.

Finally, these trends have interlinked with the recent financial and economic crises and with the slow recovery afterwards, often showing a jobless nature. In the background of this scenario, international organizations - including the UNIDO, IDB and the OECD - are increasingly concerned with the issue of avoiding jobless growth as countries recover from the crisis (see, Crespi and Tacsir, 2012; UNIDO, 2013; Arntz, et al., 2016; OECD, 2016).

In this context, Brynjolfsson and McAfee (2011 and 2014) think that the root of the current employment problems is not the Great Recession, but rather a structural adjustment (a “Great Restructuring”) characterized by an exponential growth in computers’ processing speed having an ever-bigger impact on jobs, skills, and the whole economy. By the same token, Frey and Osborne (2013) - using a Gaussian process classifier applied to data from the US Department of Labour - predict that 47% of the occupational categories are at high risk of being automated, including a wide range of service/white-collar/cognitive tasks such as accountancy, logistics, legal works, translation and technical writing, etc.

The aim of this paper is twofold. On the one hand, the economic insights about the employment impact of technological change will be disentangled starting from the classical economists to nowadays theoretical and empirical analyses; on the other hand, a sectoral empirical test will be provided, in order to shed some light on the recent evolution of the relationship between innovation and employment.

Three are the main novel contributions of this work.

Firstly, a comprehensive theoretical setting will be critically discussed through an original taxonomy, trying to reveal and focus on implicit assumptions, possible drawbacks and market failures that are often either disguised or neglected by the current economic debate, that is often prone to believe that market clearing can always guarantee a return to full employment (Section 2).

Secondly, an updated survey of previous empirical studies (at the macro, sectoral and micro level) will be provided (Section 3).

Thirdly, we will put forward a dynamic specification able to empirically test the possible employment impact of new technologies across different European countries in recent times (Section 4 and 5).

2. *Theory*

Indeed, the assessment of the effects of technological change on employment is both a well-known and a controversial issue for theoretical economists. On the one hand, technological unemployment is considered a direct worrisome consequence of labour-saving process innovations; on the other, economic theory pinpoints the existence of indirect effects able to compensate for the reduction in employment due to technological progress, together with product innovation that generally shows a labour-friendly nature.

2.1. Process innovation and the "compensation theory"

On the one hand, the direct impact of process innovation is to destroy jobs: by definition, process innovation means to produce the same amount of output with a lesser amount of production factors, mainly labour. On the other hand, since its very beginning, the economic theory has pointed out the existence of economic forces which can compensate for the reduction in employment due to technological progress.

In more detail, at the time of the classical economists, two views started to compete in assessing the employment impact of technology: using Ricardo's words, the "working class opinion" was characterized by the fear of being dismissed because of innovation (see Ricardo, 1951, p. 392), whilst the academic and political debate was mainly dominated by an ex-ante confidence in the market compensation of dismissed workers. Ironically, in the meantime the English workers were destroying machines under the charismatic lead of Ned Ludd (see Hobsbawm, 1968; Hobsbawm and Rudé, 1969), the economic discipline was trying to dispel all concerns about the possible harmful effects of technological progress, on a basis of a rigorous, counter-intuitive and "scientific" theory.

In particular, in the first half of the XIX century, classical economists put forward a theory that Marx later called the "compensation theory" (see Marx, 1961, vol. 1, chap. 13 and 1969, chap. 18). This theory is made up of different market compensation mechanisms which are triggered by technological change itself and which can counterbalance the initial labour-saving impact of process innovation (for extensive analyses and comprehensive surveys on the subject, see a Petit, 1995; Vivarelli, 1995, chaps. 2 and 3; Vivarelli and Pianta, 2000, chap. 2; Pianta, 2005; Coad and Rao, 2011; Vivarelli 2013 and 2014).

A) The compensation mechanism "via new machines"

The same process innovations which displace workers in the user industries, create new jobs in the capital sectors where the new machines are produced (see, for instance, Say, 1964, p. 87).

B) The compensation mechanism "via decrease in prices"

On the one hand, process innovations involve the displacement of workers; on the other hand, these innovations themselves lead to a decrease in the unit costs of production and - in a competitive market - this effect is translated into decreasing prices; in turn, decreasing prices stimulate a new demand for products and so additional production and employment. This mechanism was singled out at the very beginning of history of the economic thought (Steuart, 1966, vol. II, p. 256).

This line of reasoning became the cornerstone of the compensation theory when Say's law became the focus of classical economic theory (see Say, 1964, p. 87). According to this law, in a competitive world, the supply generates its own demand and technological change fully takes part in this self-adjusting process.

The compensation mechanism "via decrease in prices" has been re-proposed many times in the history of economic thought both by neoclassical (see Pigou, 1962, p. 672) and by contemporaneous economists (see Neary, 1981; Stoneman, 1983, chaps. 11 and 12; Hall and Heffernan, 1985; Dobbs et al., 1987; Nickell and Kong, 1989; Smolny, 1998; Harrison et al., 2008).

C) The compensation mechanism "via new investments"

In a world where the competitive convergence is not instantaneous, it is observed that during the gap between the decrease in costs - due to technological progress - and the consequent fall in prices, extra-profits may be accumulated by the innovative entrepreneurs. These profits are invested and so new productions and new jobs are created. Originally put forward by Ricardo[1] (1951, vol. I, p. 396), this proposition has also been called forth by neo-classicals like Marshall (1961, p. 542) and by more recent dynamic models such as those by Hicks (1973) and Stoneman (1983, pp. 177-81). The role of lagged innovation in fostering employment evolution is investigated at a microeconomic level by Van Reenen (1997) and Lachenmaier and Rottmann (2011).

D) The compensation mechanism "via decrease in wages"

In a demand-for-labour framework, the direct effect of job-destructive technologies may be compensated within the labour market. In fact, assuming free competition and full substitutability between labour and capital, technological unemployment implies a decrease in wages and this should induce a reverse shift back to more labour-intensive technologies. The first to apply this kind of argument was Wicksell (1961, p. 137), followed by Hicks (1932, p. 56) and Pigou (1933, p. 256).

In modern times, the wage adjustment is a component of partial equilibrium models such as those by Neary (1981) and Sinclair (1981) and general equilibrium analyses such as those by Layard and

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[1] It must be noticed that David Ricardo was indeed an "optimist", eventually supporting the "compensation theory", especially through the accumulation of profits. Yet, he admitted that technological unemployment can arise (see the quotation at the incipit of this work) when the adoption of new machinery with a higher capital/output ratio entails a decrease in the total national income ("gross product" in Ricardo's terminology, Ricardo, 1951, p. 390). Although Paul Samuelson (1988 and 1989) provides a mathematical proof of the Ricardian case, it is obvious that the occurrence of technological progress implying a decrease in total output is an extremely unlikely situation; indeed, Ricardo himself softened the conclusions and implications of his example and underlined its exceptionality (see Ricardo, 1951, p. 395).

Nickell (1985), Venables (1985), Layard, Nickell and Jackman (1991 and 1994), Davis (1998) and Addison and Teixeira (2001).

E) The compensation mechanism "via increase in incomes"
Directly in contrast with the previous one, this compensation mechanism has been put forward by the Keynesian and Kaldorian tradition. In a Fordist mode of production, unions take part in the distribution of the fruits of technological progress. So it has to be taken into account that a portion of the cost savings due to innovation can be translated into higher income and hence higher consumption. This increase in demand leads to an increase in employment which may compensate the initial job losses due to process innovations (see Pasinetti, 1981; Boyer, 1988A, 1988B and 1990).

2.2. A critique

On the whole, classical and current economic theorizing are characterized by an "optimistic bias", that strongly relies on market clearing. However, compensation mechanisms can be hindered by the existence of severe drawbacks which are often either neglected or mis-specified by the economic conventional wisdom. Using the same taxonomy which has been proposed above, the main criticisms of the compensation theory can be singled out as follows.

A) With few exceptions (see Hicks, 1973), nowadays this compensation mechanism is no longer put forward. Indeed, Marx's critique of this mechanism was particularly sharp:
"...the machine can only be employed profitably, if it...is the (annual) product of far fewer men than it replaces". (Marx, 1969, p. 552).

Moreover, labour-saving technologies spread around in the capital goods sector, as well; so this compensation is an endless story which can be only partial (Marx, 1969, p. 551).

Finally, the new machines can be implemented either through additional investments (see point C) or simply by substitution of the obsolete ones (scrapping). In the latter case - which is indeed the most frequent one - there is no compensation at all (see, for instance, Freeman et al., 1982).

B) As originally noted by Malthus (1964, vol. II; pp. 551-60), Sismondi (1971, p. 284) and Mill (1976, p. 97), the very first effect of a labour-saving technology is a decrease in the aggregate demand due to the cancellation of the demand previously associated with the dismissed workers. So, the mechanism “via decrease in prices” deals with a decreased demand and has to more than counterbalance the initial decrease in the aggregate purchasing power.

In addition, this mechanism relies on Say’s law and does not take into account that demand constraints might occur. In this context, Keynes’ dismissal of Say’s law is crucial: difficulties concerning some components of the “effective demand” - such as a low value of the “marginal efficiency of capital” (see Keynes, 1973, chap. 11) - can involve a delay in expenditure decisions and a lower demand elasticity. If such is the case, this compensation mechanism is hindered and technological unemployment ceases to be a temporary problem: in fact, since process innovation are continuously introduced in the economy, a delay in compensation is sufficient to create a structural unemployment that persists over time.

Finally, the effectiveness of the mechanism “via decrease in prices” depends on the hypothesis of perfect competition. If an oligopolistic regime is dominant, the whole compensation is strongly weakened since cost savings are not necessarily and entirely translated into decreasing prices (see Sylos Labini, 1969, p. 160).

C) Also the compensation mechanism “via new investments” strongly relies on the unacceptable Say’s law assumption that the accumulated profits due to innovation are entirely and immediately translated into additional investments. Again, Marx’s and Keynes’s treatment of Say’s law can be used to doubt the full effectiveness of this compensation mechanism. In particular, pessimistic expectations (“animal spirits” in Keynesian terms) may imply the decision to postpone investments even in the presence of cumulated profits obtained by innovation. Here again, a substantial delay in compensation may generate structural technological unemployment.

Moreover, the intrinsic nature of the new investments does matter; if these are capital-intensive, compensation can only be partial (see the quotation reported in the Introduction)

D) Also the mechanism “via decrease in wages” contrasts with the Keynesian theory of effective demand. On the one hand, a decrease in wages can induce firms to hire additional workers, but - on the other hand - the decreased aggregate demand lower employers’ business expectations and so they tend to hire fewer workers (on this, see also the next point).

E) During the “golden age” of the ‘50s and ‘60s the Fordist mode of production was based on a relevant change in the labour-wage nexus. Instead of leaving the wage to be regulated by a competitive labour-market, workers were allowed to take possession of a relevant portion of productivity gains due to technological progress. In turn, the increased real wages involved mass consumption and this stimulated investments leading to further productivity gains through innovation and scale economies (Boyer, 1988C). Labour-saving technologies were introduced on large scale, but the Kaldorian “virtuous circle” allowed an important compensation “via new incomes”.

Nowadays, the Fordist mode of production is over for many reasons that cannot be discussed here (see Boyer 1988C and 1990). The distribution of income follows different rules (based more on Phillips’ curve than on sharing the productivity gains) and labour markets have returned to be competitive and flexible. On the whole, this compensation mechanism has been strongly weakened in the new institutional context (see Appelbaum and Schettkat, 1995).

Summing up, economic theory cannot claim to have a clear answer in terms of the final employment impact of process innovation. Indeed, price and income mechanisms do have the possibility to counterbalance the direct job destruction caused by process innovation, but their actual effectiveness is problematic and depends on many parameters such as the degree of competition, the demand elasticity, the way how business expectations are shaped. On the whole, depending on the different institutional, social and economic contexts, compensation can be more or less effective and the technological unemployment only partially reabsorbed.

2.3. Product innovation and employment

Of course, technological change cannot be reduced to process innovation: the other side of the coin is product innovation that is also important in terms of its possible employment impact.

As far as product innovation is concerned, not much theory is needed: obviously enough, the introduction of new products and the consequent emergence of new markets (see, for instance, the automobile at the beginning of the XX century or the personal computer in the last decades of the same century) involve a job-creation effect. Indeed, the labour-intensive impact of product innovation was underlined by classical economists (Say, 1964, p.88) and even the most severe critic of an optimistic vision of the employment consequences of technological change admitted the positive employment benefits which can derive from this kind of innovation (Marx, 1961, vol. I, p.445).

In the current debate, various studies (Freeman et al., 1982; Freeman and Soete, 1987; Freeman and Soete, 1994; Vivarelli and Pianta, 2000; Edquist et al., 2001; Bogliacino and Pianta, 2010) agree that product innovations have a positive impact on employment since they open the way to the development of either entire new goods or main differentiation of mature goods.

However, even the job creating effect of product innovation may be more or less effective. In fact, the so-called “welfare effect” (the creation of new branches of production) has to be compared with the “substitution effect” (displacement of mature products; see Katsoulacos, 1984 and 1986; Harrison et al., 2008; Hall et al., 2008). For example, the MP3 music format is a product innovation currently displacing the compact disk which in turn displaced the vinyl. More in general, different “technological paradigms” are characterized by different clusters of new products which in turn have very different impacts on employment: for instance, the introduction of the automobile had a much higher labour-intensive effect than the diffusion of the home computers.

Indeed, in different historical periods and different institutional and social frameworks, the relative balance between the direct labour-saving effect of process innovation and the counterbalancing impacts of compensation forces and product innovation can considerably vary[2] (Freeman et al., 1982; Freeman and Soete, 1987; Freeman and Soete, 1994).

Summarizing the economic theory available on the subject, the relationship between innovation and employment can be represented by a very complex picture where the direct labour-saving impact of process innovation, the compensation mechanisms, the drawbacks and hindrances which can severely weaken the effectiveness of such mechanisms, and the labour friendly nature of product innovation can combine in very diverse outcomes.

Hence, although theoretical economists may develop complex models about the employment impact of innovation, the economic theory does not have a clear-cut answer about the final employment effect of R&D and innovation. Indeed, the actual employment impact of the new technologies depend on the balance between process and product innovation, the values of the different parameters assessing the efficacy of the different compensation mechanisms, the particular institutional and social context[3]. Therefore, attention should be turned to the empirical analyses.

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[2] For instance, nowadays, the role of green innovation is crucial, also in terms of likely employment impact: see Crespi et al. (2016) and Gagliardi et al. (2016.

[3] The empirical studies devoted to the relationship between innovation and employment have mainly focused on high-income countries, especially OECD countries (basically because of data availability), meanwhile only recently the phenomenon has been under investigation in developing countries (see Meschi et al., 2011, for an application to the Turkish case and Mitra and Jha, 2015, for an application to the Indian case).

3. *Previous empirical evidence*

Macroeconometric studies have tested the validity of the compensation mechanisms in a partial or general equilibrium framework.

Back in 1981 and using US data, Sinclair (1981) proposed a macroeconomic IS/LM approach and concluded that a positive employment compensation can occur, if demand elasticity and the elasticity of factor substitution are sufficiently high.

Layard and Nickell (1985) derived a demand for labour in a quasi-general equilibrium framework and stated that the crucial parameter was the elasticity of the demand for labour in response to a variation in the ratio between real wages and labour productivity. Their hypothesis is that technical change increases labour productivity and - given an adequate elasticity - proportionally the demand for labour and this can be enough to fully compensate initial job losses.

Using a similar approach, Nickell and Kong (1989) focused their attention to the operating of the compensation mechanism "via decrease in prices" in nine UK two-digit industries. Putting forward a price equation where cost-saving effects of labour-saving technologies were fully transferred into decreasing prices, results showed that in seven sectors out of nine a sufficiently high demand elasticity was able to imply an overall positive impact of technical change on employment.

In Vivarelli (1995, chaps. 7, 8 and 9) the direct labour-saving effect of process innovation and the different compensation mechanisms have been represented and estimated through a simultaneous equations model over the period 1960-1988. Running 3SLS regressions based on Italian and US data, the most effective compensation mechanism turned out to be that "via decrease in prices" in both countries. In addition, the US economy resulted to be more product oriented than the Italian economy.

Simonetti et al. (2000) applied the same simultaneous equations macroeconomic model of Vivarelli (1995), running 3SLS regressions using American, Italian, French and Japanese data over the period

1965-1993. The authors found that the more effective compensation mechanisms were that “via decrease in prices” and that “via increase in incomes” (especially in Italy and France till the mid-eighties). Finally, product innovation significantly revealed its labour intensive potentiality only in the technological leader country in the period, namely the US.

Finally, Feldmann 2013 - using data on 21 industrial countries over the period 1985-2009 - assess the impact of innovation (proxied by triadic patents normalized by population) on aggregate unemployment, controlling for a set of macroeconomic factors such as labour market features, tax wedge, employment protection, inflation and output gap. His results suggest that technological change significantly increases unemployment over a three year period, but this impact fades away in the long run.

On the whole, the (few) aggregate studies available on the subject reveal - not surprising - that technological change can display its labour-friendly nature only when markets are characterized by competition and flexibility, and particularly by higher demand elasticities (both in the product and in the labour market) and higher substitutability between the production factors.

However, country-level studies are affected by severe methodological shortcomings. On the one hand, they allow to fully explore the different direct effects and compensation mechanisms at work in the aggregate (see previous section). On the other hand, they are often severely constrained by composition biases in the data, by the difficulty to find a proper aggregate proxy for technological change and by the fact that the final employment national trends are co-determined by overwhelming institutional and social determinants difficult to disentangle and to control for.

In this context, the sectoral dimension is an alternative and particularly important setting for investigating the overall employment impact of innovation.

Overall, in manufacturing new process innovations seem to be implemented mainly through labour-saving embodied technical change, only partially counterbalanced by the market compensation mechanisms.

For instance, Clark (1983 and 1987) put forward a supply oriented vintage model investigating UK manufacturing and showed that the expansionary effect of innovative investments was prevalent until the mid ‘60s, when the rationalizing effect (due to labour-saving process innovation incorporated in investments and scrapping) started to overcome the expansionary one.

In a study using Italian data, Vivarelli et al. (1996) found evidence that in Italian manufacturing the relationship between productivity growth and employment appeared to be negative and, in particular, that product and process innovation had, respectively, positive and negative effects on the demand for labour.

Overall, the scenario may change if services sectors are considered. Pianta (2000) and Antonucci and Pianta (2002) found - using sectoral data based on the European Community Innovation Surveys (CIS) - an overall negative impact of innovation on employment in manufacturing industries across five European countries, meanwhile - in contrast - Evangelista (2000) and Evangelista and Savona (2002) found a positive employment effect of technological change (only) in the most innovative and knowledge-intensive service sectors.

Taking manufacturing and services jointly into account (again using CIS data), Bogliacino and Pianta (2010) found a positive employment impact of product innovation (which turned out particularly obvious in the high-tech manufacturing sectors - see also Mastrostefano and Pianta, 2009).

More recently, Coad and Rao (2011) focused on US high-tech manufacturing industries over the period 1963-2002 and found that innovation and employment were positively linked (especially within the fast growing firms).

Finally, Bogliacino and Vivarelli (2012) - running GMM-SYS panel estimations covering 25 manufacturing and service sectors for 15 European countries over the time-span 1996-2005 - found that R&D expenditures do show a job-creating effect, especially in high-tech industries.

Summarizing the available sectoral evidence, a labour-saving tendency emerges in low- and medium- tech manufacturing, while a dominant labour friendly impact has been detected in the high-tech manufacturing sectors and in the knowledge-intensive services, those sectors where product innovation is prevailing and where the demand evolution is more dynamic.

While the econometric test put forward in this paper will be run at the sectoral level, the literature devoted to the microeconometric investigation of the link between technological change and employment also deserves to be briefly discussed.

Indeed, microeconometric studies have the great advantage to grasp the very nature of firms' innovative activities and to allow a direct and precise firm-level mapping of innovation variables (innovation dummies, R&D, patents; etc.). However, there are limitations associated to this level of analysis, as well. Firstly, the microeconomic approach cannot take fully into account the indirect compensation effects which operate at the sectoral and country levels. Secondly, a possible shortcoming of this kind of analysis consists in an 'optimistic ex-ante bias': in fact, innovative firms tend to be characterized by better employment performances simply because they gain market shares because of innovation. Even when the innovation is intrinsically labour-saving, microeconomic analyses generally show a positive link between technology and employment since they do not take into account the important effect on the rivals, which are crowded out by the innovative firms ("business stealing" effect).

For instance, Van Reenen (1997) – using the SPRU innovation database and over the period 1976–1982 – found evidence of a positive employment impact of innovation. This result turned out to be robust after controlling for fixed effects, dynamics and endogeneity.

Interestingly enough, Greenan and Guellec (2000) – using data on French manufacturing firms over the 1986-1990 period – found that innovating firms created more jobs than non-innovating ones, but the reverse turned out to be true at the sectoral level, where the overall effect was negative and only product innovation revealed to be job-creating. This controversial employment impact of innovation at the firm and sectoral level might be due to the ‘business stealing’ effect mentioned above.

In the case of Italy Piva and Vivarelli (2004 and 2005) found evidence in favor of a positive effect - although small in magnitude - of gross innovative investment on employment (on the Italian case, see also Hall et al. (2008) finding a positive employment contribution of product innovation and no evidence of employment displacement due to process innovation).

More recently, Lachenmaier and Rottmann (2011) - using a comprehensive dataset of German manufacturing firms over the period 1982-2002 – found a significantly positive impact of different innovation measures on employment, but, partially in contrast with expectations and previous contributions, the authors found a higher positive impact of process rather than product innovation.

Turning our attention to Spain, Ciriaci et al. (2016) - using matched waves of the annual Spanish Community Innovation Survey (CIS) - run quantile regressions based on a sample of 3.304 Spanish firms over the period 2002–2009. Their results show that innovative, smaller and younger firms are more likely to experience high and persistent employment growth episodes than non-innovative firms.

Other recent studies overcome a single-country dimension. For instance, Bogliacino et al. (2012) – investigating European manufacturing and service firms over the period 1990-2008 - found a positive and significant employment impact of R&D expenditures in high-tech manufacturing and services but not in the more traditional manufacturing sectors.

Finally, using firm level data from four European countries, Harrison et al. (2014) showed that process innovation tended to displace employment (although compensation mechanisms were at work), while product innovation was fundamentally labour-friendly.

On the whole, the microeconometric evidence provides evidence of a positive link between innovation and employment, especially when R&D and/or product innovation are adopted as proxies of technological change and when high-tech sectors are considered.

4. *Data and econometric setting*

4.1 The data

We rely on a database including two-digit sectors belonging to manufacturing and market services, covering the 1998-2011 period for 11 European countries (Austria, Belgium, Czech Republic, Denmark, Finland, Germany, Hungary, Italy, Norway, Slovenia, Sweden) for a total of 3,073 observations. We use the statistical source OECD-STAN for most of the information, coupling it with OECD-ANBERD as far as business R&D is concerned.

Value added has been deflated using the sectoral deflators provided by STAN, which take hedonic prices into account. All other nominal variables have been deflated using GDP deflators. We have considered 2010 as the base year. We have corrected all the series for purchasing power parities, expressing, at the end, all the monetary values in constant prices and PPP 2010 US dollars[4].

In Table 1 we report the sectors considered and the average R&D intensity for the covered industries, measured as the ratio of R&D expenditures over value added. Since the available classifications are not fully exhaustive [5], we decided to adopt an endogenous classification based on the revealed R&D intensities, in order to have three homogeneous groups (the outcome is however almost fully consistent with EUROSTAT classification). In particular, sectors are classified as LT if R&D intensity is less than 1%; MT if it is included between 1% and 5%; HT if R&D intensity is larger than 5%. This splitting will allow us to investigate the R&D/employment nexus across the three groups of sectors, in order to test the outcome - common to the previous empirical studies - that the positive

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[4] In order to be consistent within our statistical sources, we used information provided by OECD: http://stats.oecd.org/ where both deflators, exchange rates and PPP series are available.

5 See: http://ec.europa.eu/eurostat/statistics-explained/index.php/Glossary:Hightech_classification_of_manufacturing_industries; http://ec.europa.eu/eurostat/cache/metadata/Annexes/htec_esms_an3.pdf

employment impact of innovation is detectable mainly (only) in the high-tech sectors.

Table 1: *The sectoral splitting*

Industries	**ISIC Rev. 4**	**R&D intensity**	
Agriculture, forestry and fishing	01-03	0.39	LT
Mining and quarrying	05-09	1.02	MT
Food products, beverages and tobacco products	10-12	0.97	LT
Textiles	13	2.01	MT
Wearing apparel	14	1.53	MT
Leather and related products, footwear	15	1.88	MT
Wood and products of wood and cork, except furniture; articles of straw and plaiting materials	16	0.51	LT
Paper and paper products	17	1.29	MT
Printing and reproduction of recorded media	18	0.46	LT
Coke and refined petroleum products	19	1.13	MT
Chemicals and chemical products	20	5.16	HT
Basic pharmaceutical products and pharmaceutical preparations	21	16.46	HT
Rubber and plastics products	22	2.70	MT
Other non-metallic mineral products	23	1.50	MT
Basic metals	24	2.35	MT
Fabricated metal products, except machinery and equipment	25	1.62	MT

Computer, electronic and optical products	26	22.67	HT
Electrical equipment	27	6.80	HT
Machinery and equipment n.e.c.	28	5.47	HT
Motor vehicles, trailers and semi-trailers	29	9.11	HT
Other transport equipment	30	12.40	HT
Furniture; other manufacturing; repair and installation of machinery and equipment	31-33	2.15	MT
Electricity, gas and water supply; sewerage, waste management and remediation activities	35-39	0.30	LT
Construction	41-43	0.20	LT
Wholesale and retail trade, repair of motor vehicles and motorcycles	45-47	0.30	LT
Transportation and storage	49-53	0.07	LT
Accommodation and food service activities	55-56	0.02	LT
Publishing, audiovisual and broadcasting activities	58-60	1.33	MT
Telecommunications	61	1.71	MT
IT and other information services	62-63	5.18	HT
Financial and insurance activities	64-66	0.43	LT
Real estate activities	68	0.01	LT
Scientific research and development	72	32.85	HT
Administrative and support service activities	77-82	0.11	LT
Public administration and defense; compulsory social security	84	0.00	LT
Human health and social work activities	86-88	0.15	LT

Arts, entertainment and recreation	90-93	0.06	LT
Other service activities. Activities of households as employers; undifferentiated goods- and services-producing activities of households for own use	94-98	0.05	LT

Notes: LT stands for low-tech; MT for medium-tech and HT for High-tech industries.

4.2 Econometric strategy

Since our dependent variable (employment) is highly persistent[6], as common in the recent literature using longitudinal data (since Van Reenen 1997 onward, see Section 3), we adopt a dynamic employment equation, where employment is autoregressive and depends on output (value added), wages, capital formation and R&D expenditures, which is our direct measure for innovation. Therefore, the estimated equation is a dynamic labour demand, augmented with technology:

$$\ln(\boldsymbol{E}_{\boldsymbol{ijt}}) = \rho \ln(\boldsymbol{E}_{\boldsymbol{ijt}-1}) + \alpha_0 + \alpha_1 \ln(\boldsymbol{W}_{\boldsymbol{ijt}}) + \alpha_2 \ln(\boldsymbol{Y}_{\boldsymbol{ijt}}) + \alpha_3 \ln(\boldsymbol{I}_{\boldsymbol{ijt}}) + \alpha_4 \ln(\boldsymbol{R\,\&\,D}_{\boldsymbol{ijt}}) + \boldsymbol{\beta}'\boldsymbol{C} + \gamma'\boldsymbol{T} + \boldsymbol{\varepsilon}_{\boldsymbol{ij}} + \boldsymbol{u}_{\boldsymbol{ijt}} \qquad \textbf{(1)}$$

where *i*, *j*, *t* indicate respectively industry, country and year; *E* is employment, *W* is labour compensation per employee, *Y* is value added, *I* is gross fixed capital formation, *R&D* is our proxy for technology, *C* is a set of country dummies, *T* is a set of time

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[6] Indeed, the estimation of an employment equation is the standard example for which a panel dynamic specification turns out to be the proper econometric strategy (see Arellano and Bond, 1991).

dummies, and the last two terms are the components of the error term[7].

It is well known by scholars of panel theory that the above dynamic specification cannot be correctly estimated either by Pooled Ordinary Least Squares (POLS) or by the Within Group (fixed effects, WG) estimator. Accordingly, we use Generalized Method of Moments (GMM) in the Blundell and Bond (1998) version (GMM-SYS), since our sample is characterized by high persistence and a dominant cross-sectional variability. Furthermore, we compute a robust and Windmeijer (finite sample) corrected covariance matrix.

While in a dynamic employment equation the lagged dependent variable and the wage term are obviously endogenous, high persistence suggests potential endogeneity for the other variables, as well; therefore, to be on the safer side, we instrument all of them.

We expect a positive and high coefficient for the lagged term, a negative α_1 capturing the standard labour demand inverse relationship between wages and employment, and a positive α_2 capturing the role of final demand. A priori, α_3 has no obvious sign, since capital formation is labour-expanding through its expansionary effect, and labour-saving through process innovation embodied in the new machineries (see Section 2). Finally, our main interest is in α_4, linking R&D with employment: consistently with the previous literature (see Section 3) and taking into account that R&D is more related with product rather than process innovation, we expect a positive sign for α_4 (see Section 2).

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[7] The set of country dummies control for the possible impact of different national macroeconomic climates, and specific economic policies, while the set of time dummies capture both the economic business cycle and possible supply side effects in the European labour market.

5. *Results*

As can be seen from Table 2 and focusing on the more reliable GMM-SYS estimates[8], the results exhibit very interesting patterns.

Not surprisingly, the employment variable turns out to be highly auto-correlated and value added is positively linked with employment, while wages inhibit the demand for labour (although this relationship is significant only in the preliminary POLS and WG estimates).

Together with these expected results, capital formation is negatively (and significantly at 95%) related to employment; this result points to a possible labour-saving effect due to the embodied technological change incorporated in the new investment (see Section 2). It may well be the case that in most recent years (also including the worldwide financial crisis and its consequences) the rationalizing component of investment - fostering process innovation - has turned out to dominate its expansionary component.

Turning our attention to our main variable of interest (R&D), the outcome based on the overall estimate is consistent with the previous empirical literature (see Section 3): the elasticity between R&D expenditures and employment turns out to be positive and significant (at the 95% level of confidence), albeit very small in magnitude: 0.005.

Therefore, considering all the economic sectors, R&D expenditures (linked to product innovation) show a labour-friendly nature, although their impact is almost negligible: doubling the R&D investment would induce an increase in employment by about 0.5%. In contrast, capital formation (linked to labour-saving process innovation) seem to play a more relevant role: *ceteris paribus*, an increase of 100% in investment activity in European sectors would imply a decrease of 1% in employment levels.

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[8] Pooled Ordinary Least Squares (POLS) and fixed effect estimators (WG) are provided for completeness and for showing that the estimated GMM coefficient for the lagged dependent variable is correctly situated within the upper and lower bounds set by the POLS and WG estimates respectively.

Table 2: *Dependent variable: number of employees in log scale*

	(1) POLS	**(2) WG**	**(3) GMM-SYS**
log(E_{ijt-1})	0.971***	0.755***	0.930***
	[0.005]	[0.016]	[0.031]
log(W_{ijt})	-0.013***	-0.028**	-0.042
	[0.004]	[0.012]	[0.028]
log(Y_{ijt})	0.037***	0.151***	0.096***
	[0.005]	[0.024]	[0.029]
log(I_{ijt})	-0.004*	-0.007	-0.010**
	[0.003]	[0.004]	[0.005]
log($R\&D_{ijt}$)	0.005*	0.002*	0.005**
	[0.003]	[0.001]	[0.002]
Constant	-0.368***	-0.169	-0.794***
	[0.042]	[0.458]	[0.144]
Country dummies	Yes	No	Yes
Time dummies	Yes	Yes	Yes
N Obs	3,073	3,073	3,073
Hansen			250.20
p value			0.079
N instruments			220
AR(1)			-6.74
p value			0.000
AR(2)			-1.78
p value			0.077

Notes:

- robust standard errors in brackets;
- *, **, *** indicate statistical significance respectively at 10, 5 and 1%;
- in GMM-SYS estimation all the regressors are considered endogenous and instruments include lags from two to four.

As a first extension, we have run alternative specifications in which we have replaced capital and R&D flows with stocks (respectively K and Z); in fact, it may well be the case that current employment is affected not just by the current flows of R&D expenditures and investments, but rather by the cumulated stocks of knowledge and physical capital. The K and Z stocks have been built using the perpetual inventory method (PIM)[9]:

$$K_{ijt} = \begin{cases} (1-\delta_i)K_{ijt-1} + I_{ijt} & if\ t > 0 \\ \dfrac{I_{ijt}}{g_{ij} + \delta_i} & if\ t = 0 \end{cases} \tag{2}$$

$$Z_{ijt} = \begin{cases} (1-\lambda_i)Z_{ijt-1} + R\,\&\,D_{ijt} & if\ t > 0 \\ \dfrac{R\,\&\,D_{ijt}}{g_{ij} + \lambda_i} & if\ t = 0 \end{cases} \tag{3}$$

where *g* is the 1998-2003 compound growth rate at the industry level, δ is equal to 6% and λ is equal to 15%; *I* and *R&D* are the

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[9] To initialize the PIM it is necessary to input historical capital and R&D growth rates; to avoid losing observations, we have calculated the average compound growth rates over the period 1998-2003 and used them as the growth rates for computing the initial 1998 stocks. Whenever the growth rates were negative we have used zero. As far as depreciation rates are concerned, we have used the reference rates in the literature: 15% for R&D and 6% for physical capital (see Musgrave 1986; Bischoff and Kokkelenberg, 1987; Nadiri and Prucha, 1996 for physical capital; Pakes and Schankerman, 1986; Hall, 2007; Aiello and Cardamone, 2008 for knowledge capital). For obvious reasons, the literature assumes the obsolescence of knowledge capital to be faster than that of physical capital.

flows of capital and R&D, while K and Z are the corresponding stock measures.

As can be seen in Table 3, reporting alternative GMM-SYS estimates, the demand-for-labour coefficients well behave, confirming the auto-correlated nature of the employment variable, the positive and highly significant impact of output and the negative effect of wages (although they turn out to be barely significant in these estimates).

The negative impact of capital formation is not only confirmed (third column), but also reinforced by using the stock variable K (columns 1 and 2); indeed, at least in the examined period, the complementarity between capital and labour has been dominated by a labour-saving impact, possibly due to process innovation incorporated in capital formation.

Moving to the R&D flow and stock (Z), its labour-friendly nature is fully confirmed and even reinforced: when Z is considered, the estimated elasticity increases to 0.8/0.9% and its significance rises to 99%.

On the whole, the stock estimates are consistent with the flow ones and point to a labour-friendly nature of R&D and a labour-saving impact of embodied technological change, more or less compensating each-other.

A further extension consists in using the sectoral splitting presented in Table 1, in order to investigate possible sectoral peculiarities in the relationship between innovation and employment, as detected by the previous literature (see Section 3). Indeed, the computed R&D intensity is significantly different across sectors (see Table 1) and the balance between product innovation (potentially labour friendly) vs process innovation (potentially labour-saving) is also not uniform across industries.

Table 3: *Dependent variable: number of employees in log scale (flows and stocks)*

	(1) GMM-SYS	(2) GMM-SYS	(3) GMM-SYS
log(E_{ijt-1})	0.931^{***}	0.948^{***}	0.947^{***}
	[0.031]	[0.027]	[0.028]
log(W_{ijt})	-0.042	-0.043^{*}	-0.046^{*}
	[0.029]	[0.026]	[0.026]
log(Y_{ijt})	0.096^{***}	0.086^{***}	0.087^{***}
	[0.028]	[0.026]	[0.027]
log(K_{ijt})	-0.009^{**}	-0.012^{**}	
	[0.005]	[0.004]	
log(I_{ijt})			-0.012^{**}
			[0.005]
log(Z_{ijt})		0.009^{***}	0.008^{***}
		[0.003]	[0.003]
log($R\&D_{ijt}$)	0.005^{**}		
	[0.002]		
const.	-0.764^{***}	-0.777^{***}	-0.797^{***}
	[0.218]	[0.157]	[0.158]
Country dummies	Yes	Yes	Yes
Time dummies	Yes	Yes	Yes
N Obs	3,073	2,826	2,826
Hansen	2490.90	234.26	225.56
p value	0.116	0.243	0.234
N instr	220	220	220
AR(1)	-6.56	-6.61	-6.62
p value	0.000	0.000	0.000
AR(2)	-1.76	-1.70	-1.70
p value	0.078	0.089	0.090

Notes:
- Z stands for R&D stock and K for capital stock;
- robust standard errors in brackets;
- *, **, *** indicate statistical significance respectively at 10, 5 and 1%;
- all the regressors are considered endogenous and instruments include lags from two to four.

Since this differentiation significantly reduces the number of available observations for each sectoral group and multiply the number of necessary moment conditions, we have opted for using the Least Squares Dummy Variable Corrected Estimator (LSDVC). Indeed, Bruno (2005a and 2005b) shows that - when the number of individuals is low related to the number of effects to identify and the panel is unbalanced – the LSDVC estimator performs better than the GMM ones[10].

Table 4 reports the separate LSDVC regressions for the LT, MT and HT sectors.

Previous results in terms of path-dependency of the dependent variable, significant positive impact of value added and negative impact of the cost of labour, are fully confirmed[11].

The sectoral splitting also allows throwing some light on the revealed overall negative relationship between investments and employment: this seems to be entirely due to the traditional low-tech sectors, while the link is not significant in the HT sectors and even positive in the MT ones. Therefore, a possible labour-saving effect due to the embodied technological change incorporated in capital formation appears to be specific to the low-tech sectors where competition is reached through decreasing costs (lower wages and process innovation).

This picture is consistent with what found with regard to our main variable of interest: indeed, R&D expenditures are job-creating in both the medium-tech and the high-tech sectors (with a 95% level of confidence and an elasticity raising to 1.8% in the MT and 2.6% in the HT), but not in the traditional sectors where they turn out to be not significant.

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[10] This methodology is based on the within group estimator, but corrected for its asymptotic bias (see Kiviet, 1995 and 1999; Bun and Kiviet, 2003). The procedure must be initialized by a dynamic panel data estimate and we have opted for the less demanding GMM-DIF. Robust standard errors have been obtained through bootstrapping, with 50 iterations.

[11] Interestingly enough, the negative role of wages in affecting employment seems to be limited to the low-tech sectors, where competition is mainly based on cost-saving rather than on innovation.

Table 4: *Dependent variable: number of employees in log scale*

	(1) LSDVC LT	(2) LSDVC MT	(3) LSDVC HT
$\log(E_{ijt-1})$	0.839^{***}	0.858^{***}	0.726^{***}
	[0.030]	[0.029]	[0.030]
$\log(W_{ijt})$	-0.051^{***}	-0.001	-0.015
	[0.013]	[0.006]	[0.016]
$\log(Y_{ijt})$	0.139^{***}	0.072^{***}	0.159^{***}
	[0.020]	[0.016]	[0.016]
$\log(I_{ijt})$	-0.013^{**}	0.013^{**}	-0.008
	[0.006]	[0.006]	[0.005]
$\log(R\&D_{ijt})$	0.001	0.018^{**}	0.026^{**}
	[0.001]	[0.008]	[0.013]
Time dummies	Yes	Yes	Yes
N Obs	1,194	732	500
Initial estimator	GMM-DIF	GMM-DIF	GMM-DIF

Notes:
- bootstrapped standard errors in brackets (50 iterations);
- *, ** and *** stay for a statistical significance respectively at 10, 5 and 1%.

6. *Conclusions*

The relationship between innovation and employment is far from being a simple one: as detailed in Section 2, technological change generates a direct impact and many indirect effects. On the one hand, process innovation implies a labour-saving effect, while product innovation is generally labour friendly. On the other hand, together with their labour-saving impact, process innovations involve decreasing prices and increasing incomes and these in turn boost an increase in demand and production that can compensate the initial job losses.

However, these compensation mechanisms can be hindered by the existence of severe drawbacks and their efficacy is dependent on crucial parameters and on the different institutional and socio-economic contexts.

Therefore, in different historical periods and different institutional frameworks, the relative balance between the direct labour-saving effect of process innovation and the counterbalancing impacts of compensation forces and product innovation can be substantially different. Of course, the scenario appears even more complicated - and less optimistic - when these direct and indirect impacts occur within a period of structural crisis as the current one.

Fully consistent with what obtained by the previous literature, this study also found a significant labour-friendly impact of R&D expenditures, which are particularly related to product innovation; however, this positive employment effect appears to be entirely due to the medium-and high-tech sectors, while no effect could be detected in the low-tech industries.

From a policy point of view, this outcome, which is consistent with previous studies (see Section 3), proves that the aim of the EU2020 strategy (see European Commission, 2010) - that is to develop an European economy based on R&D, knowledge and innovation - points in the right direction also in terms of job creation. However, this job creation has to be expected solely in the high-tech sectors, while most of European economies are specialized in traditional industries and this is somehow worrying in terms of future perspectives of the European labour market.

Moreover, and partially in contrast with the previous empirical evidence, capital formation (both in terms of flow and stock) was found to be negatively related to employment; this outcome points to a possible labour-saving effect due to embodied technological change incorporated in gross investment. It seems that in the recent years the rationalizing component of investment has turned out to dominate its expansionary component. Moreover, a possible labour-saving effect due to process innovation incorporated in capital formation seems to be specific to the low-tech sectors where competition is reached through decreasing costs. This scenario seems to corroborate Ricardo’s and Marx’s concerns. If these results will be confirmed by future research, this is surely matter for thought for the European policy makers.

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