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ARTICLE

Technology and Employment: Twelve Stylised Facts for the Digital Age

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Abstract

Twelve stylised facts on the relationship between technology and employment are proposed in this paper as a summary of current trends, conceptual issues, methodological approaches and research results. They include the following: (1) technology is shaped by social relations; (2) technology saves human labour; technological unemployment is a serious concern; (3) in the digital age the nature and boundaries of work are changing; (4) different technological strategies have contrasting employment effects; (5) industries differ in their employment dynamics and role of technology; (6) we can see the employment impact of technology at the firm, industry and macroeconomic levels; (7) technological change is a disequilibrium process; demand and structural change matter; (8) business cycles affect technological change and its employment impact; (9) the impact of technology is different across occupations and skills; (10) labour market conditions are relevant, but employment outcomes are not determined in labour markets alone; (11) in emerging countries employment outcomes are jointly affected by technology and catching up; (12) technology is an engine of inequality; profits benefit more than wages, wage disparities increase. They have important policy implications in several areas of public action.

Keywords Technology · Employment · Skills · Labour markets · Digital economy

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1 Introduction

The question of the employment impact of technology is as old as political economy.[1] Every few years a wave of international concern arises on the ways the evolution of technologies—today those of the digital economy—affects the quantity and quality of labour in each country, its compensation and the prospects for growth and well-being. In this paper current trends, conceptual issues, methodological approaches and research results are combined in twelve stylised facts on the relationship between technology and employment. They identify in an effective way the key issues, help us understand a complex phenomenon, and may stimulate an urgent policy debate on the challenges our societies face in a variety of fields. The twelve stylised facts are the following ones.

(1) *Technology is shaped by social relations* Technology does not 'fall from the sky', it is not 'neutral'. It is a social construction largely shaped by the logic of capitalism and by power relations in society. Scientific advances and human knowledge offer opportunities for technological innovation that may lead a nation's economy and individual firms in very different directions. Research and innovation efforts at the technological 'frontier' are combined with the adoption, adaptation and diffusion of already available technologies, shaping a country's growth trajectory. In emerging economies, choices on technology adoption are related to countries' development strategies, relying on particular advantages in terms of knowledge base, capital stock, absorption capabilities, institutional and infrastructural setting, low labour costs, social and environmental conditions, etc. The technological solutions, the resulting economic activities—private or public, market or non-market—the combinations required for the quantity and quality of capital and labour employed, the economic and social outcomes are the results of decisions of key economic players and government policies. Examples include decisions on knowledge generation, research and education, energy sources, transport and digital infrastructures, exploitation of natural resources, manufacturing technologies, health services, environmental and climate change effects. As such, key decisions on technology should be the object of national policy debates and democratic political process.

(2) *Technology saves human labour; technological unemployment is a serious concern* The history of technology is made of efforts for expanding human capabilities, replacing harder tasks and saving labour. In capitalism technology is embodied in the means of production and in the knowledge of workers. Since the industrial revolution of the nineteenth century, capitalism has developed machines and technologies that could replace human labour, reducing wage costs, accumulating capital and generating more profits. Technological unemployment is therefore a serious concern, rooted in the nature of capitalist production. The actual relevance of technological unemployment in particular times and places depends on the dynamics of development and on the rules and institutional arrangements on working time; in

[1] The stylised facts build on my previous works (Vivarelli and Pianta 2000; Pianta 2005; Bogliacino and Pianta 2010; Bogliacino et al. 2011; Cirillo et al. 2018; Franzini and Pianta 2016). I thank Valeria Cirillo, Dario Guarascio and Marco Vivarelli for continuing discussion on these themes.

phases of expansion compensating mechanisms and public policies may offset job losses associated with technological change.

(3) *In the digital age the nature and boundaries of work are changing* The evolution of technologies is best understood as a succession of techno-economic paradigms rooted in a set of major innovations that affect the direction of development. Since the 1980s, we have seen the emergence of the new techno-economic paradigm based on Information and Communication Technologies (ICTs), based on rapid improvements in knowledge, computing and communication systems, digitalisation, networks and automation of production. In this digital age the nature of work is changing, in particular in many information-based and platform-run activities, from the media to the arts, from education to many private services. What is changing are the boundaries between market and non-market goods, between private and public goods, between work and (unpaid) human activities, between waged employment and other forms of (somehow paid) work. Google, Facebook, AirB&B and Uber are major examples of businesses thriving on this transformation; conversely, Wikipedia and open source software are examples of online creation communities providing new types of public goods through cooperative unpaid activities. When we discuss the employment impact of digitalisation, we should understand the importance of all these shifting boundaries.

(4) *Different technological strategies have contrasting employment effects* There is too much talk of an indifferentiated 'technology'—affecting us all in a deterministic way—and not enough attention to the different technological strategies pursued by different actors pushing knowledge and its applications in sometimes diverging directions—just think of innovations in solar energy as opposed to coal and fracking technologies. Within a given firm, technology could mean the introduction of new products, new processes, new forms of organisation; we can identify, on the one hand, a strategy of *technological competitiveness* where new products open up new markets, leading to job creation; conversely, in a strategy of *cost (or price) competitiveness* labour-saving new processes and organisations are introduced, leading to job losses. A dominance of one or the other strategy leads to diverging employment outcomes of innovation. The measures we use for technology—and the interpretations we provide—have to identify this diversity. The diffusion in most advanced and emerging countries of innovation surveys on firms makes it possible to understand this diversity of technological efforts, moving beyond the limitations of R&D and patent data as technological indicators.

(5) *Industries differ in their employment dynamics and role of technology* Employment changes are not the same in all firms and industries. Some expand and some decline, and technology usually plays a role. The high-technology/low-technology distinction and—in a more refined way—the Pavitt's Taxonomy of industries provide useful ways for differentiating the evolution of economic activities and employment pointing out the role played by specific technological activities. The empirical evidence shows that industries with higher technological activities tend to show better employment performances, although with many exceptions in particular countries and periods. Moreover, in different industry groups the innovation–employment relationship tends to take different forms, with the job-creating effect of new products stronger in science-based industries and the job-destroying

effect of new processes stronger in traditional industries. The consideration of this heterogeneity of technologies and industries provides novel insights into the innovation–employment link.

(6) *We can see the employment impact of technology at the firm, industry and macroeconomic levels* Job changes can emerge, as a result of innovation, at the firm, industry and macroeconomic levels. Product innovation tends to have a positive job-creating effect at all levels. Firms innovating in both products and processes, however, may be successful in expanding output and jobs, but often do so at the expense of non-innovating firms, with little net job creation. Industry and aggregate studies generally point out the possibility of technological unemployment, which emerges when industries or countries see the prevalence of process innovations in contexts of weak demand and low entry of new firms. In an open economy innovation may lead to competitiveness and exports, weakening the demand constraint or, conversely, domestic demand may increase imports when foreign competitors are more innovative in terms of price or quality; the job-destroying effects of technology tend to be intertwined to those of offshoring of domestic production.

(7) *Technological change is a disequilibrium process; demand and economic structure matter* Mainstream economics is based on an equilibrium view of product and labour markets; technology is generally viewed as an exogenous factor affecting production processes; after a technology shock price and wage adjustments are expected to lead to a new labour market equilibrium. New growth theory has improved on this approach by assuming that in some firms innovation is endogenous and its effects spill over to the rest of the economy. Under these assumptions there is little room for understanding technological change and its employment effect. Conversely, disequilibrium approaches, combining Neo-Schumpeterian and evolutionary insights with the post-Keynesian perspective on the key role of demand and structural change provide the most appropriate tools for understanding innovation and its employment impact.

(8) *Business cycles affect technological change and its employment impact* Schumpeterian insights have long stressed the connection between technology and business cycles. Both innovation patterns and jobs are affected by upswings and downswings. Expansions provide space for new products, new markets, new jobs; recessions bring new processes, restructuring and job destruction. The nature of the innovation–employment relationship changes from the upswing to the downswing of the cycle. Periods of major crises—such as the years since 2008 in Europe—are moments of major structural change when weaker firms and industries disappear, new labour-saving processes are introduced leading to the loss of large numbers of low skill jobs. Only when new demand starts an upswing in the business cycle, the opportunities for introducing new products open up again, bringing with them new job creation.

(9) *The impact of technology is different across occupations and skills* Technologies are not all the same, nor jobs are. The *quality* of jobs—in terms of occupations, skills, educational levels, etc.—has to be considered when we investigate changes in employment. Contrary to long held expectations of a technology-driven upskilling of work from blue collar to white collar jobs (*skill bias technical change*), what is emerging in most countries and industries is a more polarised employment structure,

with larger numbers of managers, professionals and technicians, and more unskilled manual workers, especially in services. This trend also emerges when we look at the nature of 'tasks' performed (*routine biased technical change*) distinguishing between routine jobs—both cognitive and manual (such as those of clerks and factory workers)—that are easier to replace with computers, and non-routine activities (such as those of those of managers and gardeners). In this analysis, however, attention should be paid to the hierarchies in place—in terms of power, control over work and remuneration—and the occupational structure sheds more light on current change than a focus on 'tasks'. These developments are the current manifestation of a fundamental characteristic of capitalism—its tendency to introduce technology in ways that allow less skilled (and lower paid) labour to be used. The emergence of a more polarised occupational structure has major implications for educational requirements and welfare policies, and is likely to be problematic in terms of wage levels, inequality and prospects for social mobility.

(10) *Labour market conditions are relevant, but employment outcomes are not determined in labour markets alone* The importance of efficient and flexible labour markets as a tool for reducing unemployment is emphasised by mainstream approaches and policies; their view is that the impact of technology is more positive when firms easily find the desired quantity and quality of workers with low wages and moderate employment protection rules. In fact, the impact technology has on jobs is determined when innovations are designed and when labour demand takes shape, well before transactions on the labour market take place. Their role is clearly important in assuring an appropriate match between labour demand and supply in terms of education and skills levels; in finding wage levels that encourage productivity improvements and their appropriate distribution between labour and capital; in developing labour market institutions that may encourage innovation. The process of technological change, in fact, is shaped by social relations—including the balance of power between capital and labour—that are reflected in the way labour markets operate.

(11) *In emerging countries employment outcomes are jointly affected by technology and catching up* The construction of technological capabilities is a crucial component of the development process; it can be achieved through the acquisition and adaptation of foreign technologies; participation in global production networks organised by multinational firms; development of a domestic knowledge base and innovative potential. For many emerging countries the availability of innovation surveys comparable to European ones has made it possible to document the diversity of technological strategies that are carried out. A major trade-off has emerged between the acquisition of foreign technology and efforts for developing domestic R&D. The employment impact is driven by complex and contrasting forces; the acquisition of foreign machinery may introduce the same labour-saving bias found in advanced countries; once emerging countries reach some technological capability, they may enter export markets with a large potential for job creation; catching up in productivity levels may reduce employment; achieving independent capabilities may open up the possibility to reap the job creating benefit of product innovation. Still, for emerging economies the structural problems are likely to be more serious, and the compensation mechanisms less relevant than in advanced countries, possibly

making the employment impact more problematic. Four trajectories linking innovation, development patterns and employment can therefore emerge: technological dependency; imported technological capabilities; integration in international technology networks; independent technological capabilities.

(12) *Technology is an engine of inequality; profits benefit more than wages, wage disparities increase* Income inequality has reached record levels in most advanced and emerging countries and is now a major economic and political challenge. In the last three decades in many economies, national income has experienced a shift of 10–15 percentage points from wages to profits; productivity growth is leaving behind wage growth; poverty rates increase. The way technology has driven economic change is part of the problem; new product and markets allow large profits; new processes lead to job losses and lower wages; more precarious jobs and lower employment protection reduce labour costs; digital platforms allow new forms of low-wage work outside labour contracts. In most countries policies—on technology, trade, industry, labour markets, taxation, welfare expenditure, etc.—have favoured such increase in disparities, resulting in major economic and political problems. Even the OECD now acknowledges that 'when income inequality rises, economic growth falls'. Radically new policies should ensure that labour may benefit from innovation and productivity in the forms of higher wages, lower working hours and improved working conditions.

(1) Technology is shaped by social relations

The first stylised fact we propose is a way to conceptualise technology that has to be made explicit before the investigation of its economic and employment impact. Much economic research treats technology as exogenous, often with the (unrealistic) properties of a public good. In fact, technology itself deserves a close investigation, identifying the mix of public and private knowledge that supports its development. Studies on particular technologies, on discoveries, inventions and the introduction and diffusion of particular innovations have shown the complexity and uncertainty of such processes. Existing technologies have been shaped by institutional and social contexts, government policies, business strategies, technology push and demand pull effects. Different countries and firms have often made different technological choices in their investment in particular industries, in the hope to become the 'standard' and the dominant market player. Just think of the current choices world automobile firms face on the source of power—gasoline, diesel, gas, electricity, hybrid or hydrogen. Mistakes and failure are the rule rather than the exception. The process of 'creative destruction' identified by Joseph Schumpeter is an effective tool for understanding such developments.

In exploring the employment impact of technology, our starting point has to be a view of technology as a social construction, shaped by the logic of capitalism and by power relations in society.

(2) Technology saves human labour; technological unemployment is a serious concern

Stylised fact 2 deals with the fundamental economic function of technology. While technology has always been developed with the aim to expand human capabilities, in capitalism, the introduction of machines and successive waves of technologies have followed a specific logic. Technology is embodied in the means of production and in the knowledge of workers; machines are generally designed to save and expand the reach of human labour, reducing wage costs, allowing greater capital accumulation and higher profits.

For two centuries, a major positive effect of technological change has been reducing the quantity of human labour required by economic activity. The average annual working time of workers has rapidly declined; in the last three decades, however, this reduction has stopped and has been reversed in many countries. Instead of distributing the benefits of innovation and productivity gains in terms of shorter working hours for all—with constant wages—we have less people working longer hours, while unemployment is high. This is the preferred outcome for capital, setting its own rules for the employment of labour; previous declines in working hours were the outcome of social conflict and political decisions, creating complex institutional arrangements and social rules regulating the use of labour. The lack of political and social action on this issue is turning the liberating potential of innovation into a difficult problem of technological unemployment.

The debate on these issues started with the industrial revolution. At the end of the eighteenth century, James Steuart drew attention to the difficulty of reabsorbing the unemployment caused by mechanisation, in spite of the positive effects from the construction of new machines and price reductions, and already envisioned a role for the government. Adam Smith linked the invention of machines to the division of labour and emphasised its labour-saving effects. Jean-Baptiste Say had no doubts about the ability of markets to adjust, while Thomas Malthus emphasised the positive effects resulting from the strong demand dynamics experienced by England at the time. The optimism of classical economists in the early nineteenth century contrasted with the impoverishment of the English working classes—industrial workers, small artisans and displaced peasants—who had started to organise trade unions and to launch Luddite struggles against the job losses and deskilling brought about by mechanisation. David Ricardo was convinced that the economy could compensate the negative employment effects, but in a passage in the chapter ‘On machinery’, added in the third edition of his Principles of Political Economy and Taxation, argued 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 1951:392).

Karl Marx emphasised the losses for workers in terms of jobs, skills, wages and control over their work resulting from the way mechanisation was proceeding at the time and argued that unemployment grows as technical change displaces labour more rapidly that the accumulation of capital demands new workers. Marx viewed capital accumulation as a constant search for new production techniques and new products (a key starting point for the work of Schumpeter). High unemployment assures lower wages and greater control over workers; along this road, however, capital accumulation ultimately encounters the problems of finding adequate markets and demand (Heertje 1973; Vivarelli 1995, 2014; Pianta 2005). Marx had clear that the textile machines of the industrial revolution in England had their employment impact at the global level, also on the cotton artisans far away in the British empire and quoted the British Governor General reporting from India in 1834–35: 'the misery hardly finds a parallel in the history of commerce. The bones of the cotton-weavers are bleaching the plains of India' (Marx 1961, p. 389).

The possibility of technological unemployment is therefore a fundamental characteristic of capitalism. In a global economy the expansion offered by new technologies and the dislocations they introduce on previous production systems may take place in different locations. The possible 'compensation mechanisms' that may mitigate technological unemployment are discussed in Stylised fact 6, where the macroeconomic dimension is addressed.

Machines and technologies also require new types of labour, new forms of work organisation. Marx's argument that capitalism has a tendency to take the control of the labour process away from workers and transfer it to machines, expanding the power of capital over labour has been made again by Braverman (1974) in the context of Fordist-type mass production in the USA, where a 'degradation of work' could be identified.

In the age of Information and Communication Technologies, the potential for enriching or deskilling work has been pointed out by several studies. Adler (1992) found that both processes take place as a result of different strategies of firms, suggesting that 'the use of new technologies will in general be more profitable when entrusted into more highly skilled employees' (id. p. 3) with broader roles, greater competences and continued learning. However, it has been argued that 'there is a fundamental contradiction between the potential of computerization to enrich working life and increase productivity and the development of the technology in the pursuit of authoritarian social goals' (Shaiken, 1984, p. 5) as management has often introduced new technologies and shaped work organisation with the primary aim to increase control over workers (see also Noble 1984). The intensification of work is a frequent outcome, with firms pressuring workers to produce more effort; this is the result of the increased possibility to monitor work through ICTs, the weakening or absence of trade unions and overall changes in social relations and attitudes to work. In a recent book, Brynjolfson and McAfee (2014, p. 10–11) argue that 'rapid and accelerating digitization is likely to bring economic (…) disruption, stemming from the fact that as computers gets more powerful, companies have less need for some kinds of workers. Technological progress is going to leave behind some people, perhaps even a lot of people, as it races ahead'. Technological unemployment, in short, is among us, and requires a careful understanding of its mechanisms and remedies.

(3) In the digital age the nature and boundaries of work are changing

Stylised fact 3 identifies key changes in the nature of work that are emerging in the digital age. The most appropriate concept for understanding the economic role of technology is that of techno-economic paradigms (Perez 1983, Freeman and Louçã 2001). Building on the work of Kondratieff and Schumpeter, we can argue that capitalist development is characterised by a succession of techno-economic paradigms based on a cluster of core technologies with a major diffusion potential across the economy and with rapidly reducing costs. Steam power and the textile machines of the industrial revolution were the key elements of the first techno-economic paradigm; the present one has emerged in the 1980s and is based on Information and Communication Technologies (ICTs), with a current acceleration in digitalisation, networks and automation of production.

The way labour is used in our digital age differs significantly from the previous techno-economic paradigm of ‘Fordist’ mass production that had emerged in the 1940s and declined in the 1970s. ICTs and digitalisation have changed the boundaries between market and non-market goods, between private and public goods, between work and (unpaid) human activities, between waged employment and other forms of (somehow paid) work.

AirB&B is turning a spare room in the house from a gift to a friend into a market good to be sold, requiring a new type of ‘self-employed’ work mixed with social interaction. Some market goods have been replaced by non-market activities, with job destruction on the one hand, and free access to improved goods and services on the other hand—the creation of knowledge as a public good in Wikipedia is carried out by unpaid online cooperative efforts, as opposed to paid work for producing and selling the Encyclopaedia Britannica. Leisure-type communication by individuals has been turned by companies such as Facebook into a profitable activity exploited for advertising and market services. As new digital platforms emerge organising work for thousands of people—such as Uber for driving services—the nature of work changes, with an appearance of occasional ‘self-employment’ and a reality of complete control by the platform corporation.

In the European context much attention is now devoted to the ‘Industry 4.0’ perspective where large firms and government policies invest in accelerating digitalisation and automation of manufacturing and services, with important efforts in the areas of robotisation, ‘Big Data’, ‘Internet of things’, ‘Cloud computing’ and ‘platform economy’. This model of digitalisation and automation raises major challenges to the future of work in terms of quantity and quality of jobs, education and training, employment contracts, career prospects, social security implications, union protection and broader social relations (Guarascio and Sacchi 2018; Acemoglu and Restrepo 2017).

(4) Different technological strategies have contrasting employment effects

Stylised fact 4 emphasises the heterogeneity of innovative efforts. The diversity in the possible trajectories of technological change means that the economic analysis of technology has to investigate the specific innovations that are introduced in the context of particular business and development strategies. This may concern a country’s growth trajectory, an industry’s evolution or a firm’s strategy. The Schumpeterian distinction between new products, new processes and new organisational forms in firms is crucial for identifying such heterogeneity. We have an innovation when a firm first markets a new product or introduces a new process;

the road open to followers in the same industry (in other countries, too) is the imitation of new products (perhaps with incremental improvements, and adaptation to new users' needs); firms in all sectors may decide on the adoption of new processes or use of new (intermediate) products generated in other industries (and/or countries). The latter two lead to the diffusion of innovations throughout the economy, in both production and consumption.

These types of innovation greatly differ in their nature, economic relevance and labour market impact. Product innovations (in both manufacturing and service industries) can be based on internal innovative activities as well as on the acquisition of new intermediate or capital goods. They may replace old products or may be designed in order to reduce costs, with little or no net effect on employment, skills and wages. On the other hand, new products meeting a demand with high elasticity may expand output, leading to job creation; may increase variety and quality, leading to skill upgrading; both developments may turn a part of the productivity increases into higher wages.

Process innovations (including those in the delivery of services) usually replace labour with capital (often with new investment based on information and communication technologies), leading to efficiency gains and job losses (Pianta 2001, 2005). When the new products are investment goods, they represent a product innovation in the industries producing them, and process innovations in the industries acquiring them, with contrasting effects on jobs (Edquist et al. 2001).

This heterogeneity of innovation can be summarised in different technological strategies (Pianta 2001):

(a) a strategy of *technological competitiveness* where firms or industries carry our R&D, introduce new products, open up new markets, searching for quality and technological advantages; this may result in job creation (if new products are not simply a substitution of old ones);

(b) a strategy of *active cost (or price) competitiveness* where new processes and organisations are introduced with the aim to replace labour, reduce costs, restructure production and improve price competition; this generally results in job losses.

(c) a strategy of *passive cost (or price) competitiveness* where no significant innovation is introduced and firms try to compete mainly on the basis of labour cost reductions.

While in innovating firms and industries, new products and new processes often coexist, it has been shown that it is possible to identify the dominant strategy that shapes employment effects (Pianta 2000).

In order to identify this heterogeneous technological strategies, however, empirical analyses have to move beyond the use of R&D, patent data or the adoption of ICTs as technological indicators and use data from innovation surveys on firms, that are now available not only for Europe, but also for a large number of emerging countries (see Stylised fact 11 below). Innovation surveys (based on the OECD-Eurostat Oslo Manual and on the Bogota Manual) provide information based on surveys that are representative of the universe of firms that document the presence of innovation in products, processes and organisations; the expenditure for innovation (R&D, design, new machinery, marketing, etc.); the objectives that are pursued (from opening up new markets to reducing labour costs); the barriers to innovation; the share of

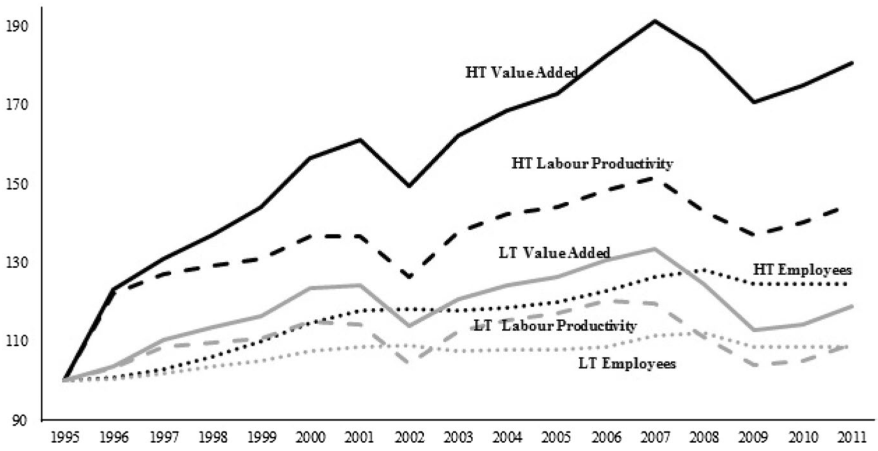

Fig. 1 Value added, employment and labour productivity in high-technology and low-technology manufacturing and service sectors in five major EU countries (DE, ES, FR, IT, UK). *Source*: Cirillo (2016a), OECD STAN data

sales associated with new products and their degree of novelty (new for the firm only or new for the relevant market); the relevance of policies, and many other aspects.

By using this approach, it is possible to break down the view of an undifferentiated technology affecting employment and to test the contrasting employment effects of strategies of technological or cost competitiveness. A large evidence is now available on European countries showing that manufacturing and service industries where product innovation is important in driving technological competitiveness have positive employment effects. Conversely, labour-saving cost competitiveness efforts lead to job losses. The employment consequences of product and process innovations are visibly different in terms of the ex ante objectives of firms' innovative strategies, in terms of ex post introduction of innovation by firms, and in terms of the specific impact on sales. (Pianta 2000; Antonucci and Pianta 2002; Mastrostefano and Pianta 2009; Bogliacino and Pianta 2010). The diversity of innovation in emerging countries is discussed below in Stylised fact 11.

(5) Industries differ in their employment dynamics and role of technology

Stylised fact 5 looks at the heterogeneity of industries in terms of their technological activities and innovative strategies. The distinction between high and low technology industries and firms is frequently used in order to identify activities where knowledge and innovation are more important. Figure 1 shows the long-term evolution of value added, employment and labour productivity in high-technology and low-technology manufacturing and service sectors in five major EU countries. In high-technology industries value added has almost doubled between 1995 and 2007, with downturns in the crises of 2002 and 2008–2009; employment has increased by about 25% only, with major productivity improvements. Conversely, low-technology

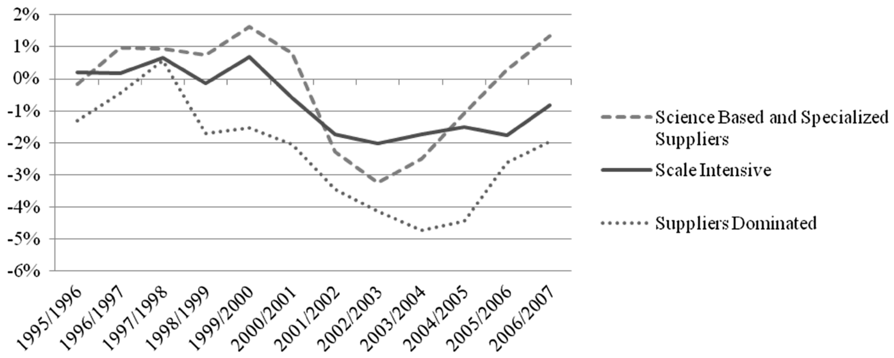

Fig. 2 Rates of change of employment in Revised Pavitt classes in six major EU countries (DE, ES, FR, IT, NL, UK). *Source*: Lucchese and Pianta (2012), OECD STAN data

sectors showed a value added growth of about 20% with a very modest dynamics of employment and productivity. The importance of innovation and the more sustained demand dynamics for high-technology productions are clear factors behind these contrasting patterns.

A more careful investigation, however, can group manufacturing and service sectors in the four categories of the Revised Pavitt's Taxonomy (Pavitt 1984; Bogliacino and Pianta 2010) that provides a relevant conceptualisation of the differences in the process of technological change by classifying firms and industries on the basis of their dominant sources of innovation, the forms of appropriation of technology and market structure. The four groups include the following:

(a) Science-based industries include sectors based on advancements in science, where R&D is the main source of innovation such as chemicals and pharmaceuticals, office machinery, R&D and business services. High technological opportunities are associated with a strong internal innovative effort. Together with specialised supplier sectors, they represent the most innovative sectors and a source of innovation for the whole economic system.

(b) Specialised supplier industries create specific products for users-industries, and these typically include machinery and equipment and consultancy services, with an active role for human capital. High levels of Research & Development expenditure (R&D) and a tacit transferring of knowledge among workers characterise a strong internal innovation process.

(c) Scale- and information-intensive industries include sectors characterised by large economies of scale, high capital intensity and strong relevance of organisational improvements such as motor vehicles, rubber and plastic products, banking services.

(d) Supplier-dominated industries include traditional sectors (including food, textiles, clothing and traditional services); they typically direct efforts towards the mechanisation of productive processes; innovation principally sources from suppliers of equipment and materials.

Figure 2 shows the rates of change of employment in Revised Pavitt classes in manufacturing in six major EU countries. Science-based and specialised supplier industries—the most innovative ones—have some growth of jobs from 1996 to 2000, with a steep fall in the crisis of 2001–2003 and a recovery up to 2007. Scale-intensive industries have stagnant employment up to 2000 and job reductions up to 2% per year in the following years. Supplier-dominated traditional industries have continuing job losses reaching − 5% in 2004–2005. Can we identify the specific role of technology in these contrasting trends?

When the analysis of the innovation–employment link is carried out separately for each industry group, different mechanisms can be identified. Considering 38 manufacturing and service sectors in eight major European countries in 1994–2004, the following results have emerged. The (modest) expansion of employment in science-based sectors has been driven by new products and by the net entry of new firms, while labour-saving process innovation has no significant effect. In specialised supplier industries weaker positive effects of new products and stronger negative effects of new processes have been found. Scale- and information-intensive sectors and the traditional industries grouped in the supplier-dominated category have recorded net jobs losses that are explained by labour-saving new processes and wage growth, while the increase in demand is the only factor supporting job creation (Bogliacino and Pianta 2010).

These findings suggest an important role of heterogeneity in industries—an even greater one can be found for firms—and point out the relevance of sectoral studies for identifying the specific relationships between innovation and employment.

(6) We can see the employment impact of technology at the firm, industry and macroeconomic levels

Stylised fact 6 stresses a methodological point—the impact of innovation on the quantity and quality of employment can be assessed at the firm, industry and macroeconomic levels. At each level of analysis we focus on a specific context and approach and we can shed light on different relationships (Pianta 2005).

The firm level The most direct employment impact of innovation is found in the firms that introduce them; the available evidence suggests that firms innovating in products, but also in processes, grow faster and are more likely to expand their employment than non-innovative ones, regardless of industry, size or other characteristics. In the case of new products, the job-creating effect is associated with expanded output (as an example of this approach see Vivarelli et al. 1996). In the case of new processes, the resulting productivity gains may lead to price reductions, larger market shares, higher output, requiring new employees. However, firm level studies cannot identify whether the gains of innovating firms are made at the expense of competitors (the business stealing effect), or whether there is a net expansion in overall jobs. Moreover, firm level studies are frequently carried out on panels that are not representative of the universe of firms; they tend to focus on manufacturing firms alone; entry or exit of firms left outside the panel may account for a large part of employment change; in this context generalising the results of firm level studies may be problematic.

The industry level Industry level studies can account for the direct effects in firms and for the indirect impact within industries, including the competitive redistribution of output and jobs from low to high innovation intensive firms, and the evolution of demand (and therefore output and jobs) resulting from the lower prices due to innovation, given the price elasticities of the industry's goods. The industry level allows to differentiate between the variety of technological regimes and strategies and, on the other hand, to bring in the demand dynamics of specific sectors, taking into account country differences in economic structures. Innovation generally has a net job-creating effect in those manufacturing and service industries showing high demand growth and an orientation towards product innovation, while a dominance of new processes may result in job losses. The overall employment effect of technology depends on the countries and periods considered, but in general is more positive the higher demand growth and the industry's technological level, the greater the entry dynamism of new firms, and the orientation towards new products. Differently from the analysis of firms, whose demand is expected to be highly elastic, an industry's demand is constrained by the (relatively slow) evolution of domestic and foreign demand; countries with a greater economic dynamism are likely to receive a disproportionate part of the employment benefits of technology, leaving to countries with lower innovation the burden of greater job losses (as examples of this approach see Pianta 2000; Bogliacino and Pianta 2010). It should be pointed out that in this regard service industries do not differ substantially from manufacturing (Evangelista and Savona 2002, 2003; Bogliacino et al. 2013).

The macroeconomic level The most complete view of the employment impact of innovation is provided by a macroeconomic perspective that can integrate all the indirect effects through which technological change affects employment—changes in prices and quantities of goods; shifts in demand patterns, investment capability and interest rates; differences in international openness of the economy; changes in wages and amount of jobs.

This is the approach typical of the debate on 'compensation mechanisms'; a comprehensive investigation on their relevance has been carried out by Vivarelli (1995), Simonetti et al. (2000). The compensation mechanism via decrease in prices has emerged as the most important one: new technologies may make lower prices possible, increasing international competitiveness and output, offsetting job losses due to the original innovation. This outcome, however, is contingent on the lack of demand constraints, on the decision of firms to transfer in lower prices the productivity gains due to the innovation, and on the lack of oligopolistic power in the relevant markets (Sylos Labini 1969).

The compensation mechanism via new machines may create jobs in the industries in which the new means of production are made, responding to the increased demand for equipment by users. However, the rationale for mechanisation is by definition saving on the overall use of labour, putting a limit on the relevance of this mechanism.

The compensation mechanism via new investment argues that the temporary extra profits available to the innovator may be turned into new investment if profit expectations are favourable (and assuming that Say's law operates); this, however, may expand production capacity and jobs, or may introduce additional labour-saving effects.

The compensation mechanism via decrease in wages is typical of the neoclassical view of the labour market. As technological unemployment appears, wages should fall and firms should hire more workers. This mechanism, however, is based on strong assumptions as to the feasibility of any combination of labour and capital, competitive markets, flexibility of wages and labour markets.

The compensation mechanism via increase in incomes operates in the opposite way, through the increased demand associated with the distribution of part of the gains from innovation through higher wages, as has happened in large, oligopolistic firms in mass production industries. However, any wage increases can hardly be large enough to sustain additional aggregate demand.

Finally, new products may lead to new economic activities and new markets (welfare effects) or, on the other hand, they may simply replace existing goods (substitution effect); in a dynamic economy—such as the USA—this effect could be significant (Vivarelli 1995). While this approach is the most comprehensive and satisfactory for explaining the overall impact of technological change on employment, the complexity of the construction of the model, the problems in specifying all relevant relationships, and the lack of adequate data limit the feasibility of this approach.

Simulation studies The employment impact of innovation has also been studied through the use of a simulation approach. Leontief and Duchin (1986) have found that the diffusion of computer technology and automation in the USA economy would have negative employment effects; their analysis was based on an input–output model incorporating strong assumptions on the productivity-enhancing effects of process innovation, but no demand dynamics. A general equilibrium model with a sectoral structure, which assumes full employment, has been used for simulating the employment impact of different scenarios of technology-based productivity growth and of the composition of consumption, in a study by IPTS-ESTO (2001) on the European Union. The results show an overall positive impact on jobs, differentiated according to the alternative sectoral distributions of R&D and innovation efforts; the best outcomes result from the concentration of efforts in high technology industries.

While they are interesting as explorations of alternative futures, the results of such simulations are weakened by the models' inability to identify either technological unemployment (when general equilibrium or DSGE models are used) or most compensation effects (when input–output models are used), and on the arbitrariness of the assumptions on the diffusion and productivity of new technologies.

In sum, technological unemployment can be detected at the industry and macroeconomic level and is generally associated with low demand dynamics, lower technological activities or high international competition in high-technology industries, and a dominance of process innovations. In open economies the generally positive role of new products and demand has to be combined with the importance of national specialisations, economic structures and the intensity of international competition, resulting in winners and losers in terms of job creation. A large attention has also been devoted to the combined employment effects of technology and globalisation; offshoring of domestic production can have a similar job destruction effect as technology in advanced countries, creating jobs in emerging economies (Bramucci et al. 2017; see Stylised fact 11 on the latter).

(7) Technological change is a disequilibrium process; demand and structural change matter

Stylised fact 7 moves to the level of economic theories, discussing how they have addressed the innovation–employment nexus. Mainstream economic approaches are based on an equilibrium view of product and labour markets; technology has long been considered as an exogenous factor affecting the whole economy with new production techniques that require changes in the combinations of capital and labour. Price and wage adjustments ensure that equilibrium in labour markets is achieved; the ‘natural’ rate of unemployment may increase, but the presence of technological unemployment is ‘assumed away’ in this approach. The ‘new growth theory’ has introduced some improvements with models where innovative efforts—proxied by technology, learning and education—are endogenous in a subset of the economy and ‘spill over’ to non-innovating firms, opening up the possibility of unemployment effects. In these perspectives unemployment is essentially considered as a labour market phenomenon, ignoring both technological unemployment and Keynesian unemployment—due to a lack of aggregate demand. Concern is mainly on the flexible operation of labour markets; downward changes in wages and labour conditions are expected to eliminate unemployment. Labour economists, in turn, have explained changes in employment and wages with main reference to the demography of jobs, macroeconomic factors, wage costs, bargaining modes and the flexibility of labour markets. The usual assumption is that of general (or partial) equilibrium of markets, that is, all output finds its demand, and all workers ready to accept the current wage find employment. Technological change is often reduced to new production processes (and new production functions), with models rarely envisaging the emergence of product innovation. When employment losses appear, they lead to downward adjustments in wages and a new equilibrium; when this is not achieved, responsibility is attached to the lack of flexibility of labour markets, with excessive union power or institutional rigidities, such as the minimum wage.

The impact of technological change cannot be understood within such a framework. Technology is by definition a disequilibrating process, long pointed out by Marx and Schumpeter. Approaches that have built on such insights include the following:

(a) *Neo-Schumpeterian approaches* have developed the concept of techno-economic paradigms, associated with long waves of capitalist developments. The rise of the paradigm based on Information and Communication Technologies creates and destroys a large amount of jobs; employment expansion can be expected only once the mismatches between the new technologies and the old economic and social structures and institutions are overcome, with a two-way adjustment. Innovation has to be adapted to social needs and economic demands; economic and social structures evolve under pressure from new technologies. New technologies need to be matched by organisational changes, new institutions and rules, learning processes, the emergence of new industries and markets, and the expansion of new demand. A long adjustment process is required, and persisting mismatches can lead to unemployment (Freeman et al. 1982; Freeman and Soete 1987, 1994; Freeman and Louçã 2001).

(b) *Evolutionary perspectives* have argued that technologies improve through innovations that expand variety and through selection in market processes; the emphasis is put on change rather than equilibrium and the role of heterogeneity, path dependency, feedbacks loops is emphasised. As analytical tools simulation and models based on heterogeneous interacting agents are often used (Nelson and Winter 1982; Dosi et al. 1988). This approach offers an appropriate understanding of the process of technological change, but has not yet produced detailed studies of its employment impact.

(c) *Post-Keynesian views of structural change* emphasise the importance of demand in driving economic growth and the importance of a country's sectoral structure; industries are assumed to grow or decline on the basis of the joint evolution of technology on the one hand and demand on the other (Pasinetti 1981). A strong expansion of demand—both domestic and foreign—offers room for creating new economic activities and jobs alongside the job destruction resulting from technology; new products tend to be introduced in phases of expansion when they can more easily meet new demand. A country's success in job creation, however, also depends on its economic structure, reflecting the relative importance of high and low tech activities and the type of innovations that are introduced (Bogliacino et al. 2013, see Stylised facts 4 and 5 above).

The process of structural change, with countries' different abilities to contract declining industries and expand production and employment in emerging ones, plays a major role in explaining employment performances. Better outcomes are found in countries with a greater activity in sectors with fast growing (at the world level) demand and output, and with greater ability to reshape their economic structures. Worse outcomes are found where a larger part of employment is in industries more exposed to the negative impact of labour-saving technological change and globalisation, and where more rigidities exist in the economic structure.

Over the past three decades in this regard Europe and the USA have evolved along opposite patterns. The USA has experienced faster growth of population, labour supply and GDP than Europe, with the expansion of new sectors based on product and service innovations, in more competitive labour markets where less regulation on minimum wages and union power are found. This has resulted in a faster growth of new jobs (compared to Europe) at the top and bottom end of the skill structure, and this polarisation has been amplified in terms of wage inequalities by the lower regulation of USA labour markets. Conversely, in Europe lower demand and greater competitive pressure have led to a slower dynamics of GDP and jobs; this macroeconomic context has led firms to favour new process technologies that have significantly reduced low skill employment, with little room for new job creation; wage polarisation has at first been mitigated by stronger European rules on wage setting and employment protection, but in the last decade labour reforms in most EU countries have moved in the direction of more precarious work, lower protection and greater wage disparities (see ILO 2015).

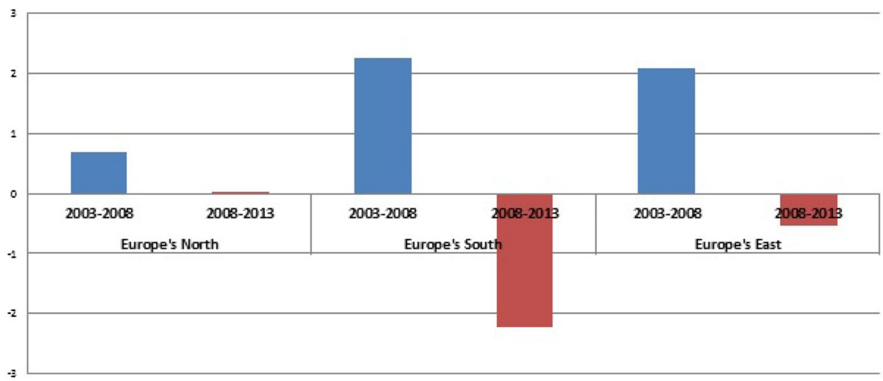

Fig. 3 Employment change over the business cycle by country groups in Europe. Average annual growth rates, percentage change

In the conclusions of our book '*The employment impact of innovation*', writing in 2000, before the introduction of the euro, we wrote that 'within the European Union, the current constraints on the expansion of demand, set by the terms of the European Economic and Monetary Union may turn out to be serious factors preventing the evolution of economic structures towards a direction more consistent with the potential offered by technological change' (Pianta and Vivarelli 2000, p. 211). The low economic and employment growth of Europe since then—and in particular after the 2008 crisis—confirms how important an expansionary macroeconomic policy is in order to capture the potential employment benefits of technology.

(8) Business cycles affect technological change and its employment impact

Stylised fact 8 introduces the time dimension. Capitalist development takes place in cycles; expansions of production bring new jobs, recessions lead to job losses. Technology too develops in cycles; expansions provide space for new products, recessions bring new processes and restructuring. The effects of cycles can be huge, as happened in Europe after the 2008 crisis; in 2008–2014, more than 6 million jobs were lost in Europe (EU 28) and 4 million in Greece, Spain, Italy and Portugal alone. Figure 3 shows how uneven the employment impact of the crisis has been in the EU, with no net job loss in Northern EU countries, limited losses in Eastern economies and the heaviest impact in the countries of Southern Europe, where a significant job growth had taken place in pre-crisis years.

Figure 4 shows the same cyclical effects for the occupational structure of major European countries (skills are addressed in Stylised fact 9 below); in the expansion more polarised jobs emerged; in the recession a major destruction of low skill blue collar jobs took place. These trends are accompanied by different technological strategies; in expansions new products may open up new markets and offer new jobs, while in recessions new processes may come to dominate technological change, leading to restructuring and job losses.

Fig. 4 Employment change over the business cycle by professional groups. Average annual growth rates, percentage change, five major European countries (DE, FR, IT, ES, UK)

The analysis of these cyclical patterns has been carried out by looking at the impact specific innovations have on jobs in the different phases of the business cycle (Lucchese and Pianta 2012; Cirillo et al. 2018). Mainstream views include Real business-cycle approaches that have assumed technology shocks as sources of fluctuations in growth (Galì 1999); endogenous growth studies assumed that downswings can stimulate productivity through a restructuring that eliminates inefficient firms (Aghion and Saint-Paul 1998). As described by Stiglitz (1993), during upswings retained profits can allow firms to overcome the financial constraints to innovation.

Conversely, neo-Schumpeterian perspectives have emphasised the role of business cycles and long waves as fundamental aspects in the emergence and diffusion of technology. For Schumpeter, innovation is uncertain and discontinuous; expansion, in turn, is uneven and unbalanced (Schumpeter 1934). For Mensch (1979), innovations are introduced in bundles during depressions: in upswings, firms can exploit rents from a higher demand for existing products; in a downswing, expected profits are lower and introducing innovations appears as a more attractive strategy. Kleinknecht (1982) emphasised the role of depressions in stimulating innovations, although the evidence is uncertain. For Freeman (Freeman et al. 1982; Freeman and Louçã 2001), depressions can increase incentives to innovate, but strong demand with expanding markets creates high expectations of profits and important opportunities for the introduction of major innovations leading to the expansion of employment in emerging industries. Freeman also suggested that business cycles could have an impact on the type of innovations introduced in the economy; product innovation is associated with phases of strong growth, while process innovations seem to be 'more attractive to entrepreneurs in periods of pressure on profit margin and during the downswing of long waves and even in depressions' (Freeman et al. 1982, p. 4; Freeman and Louçã 2001).

Recent empirical evidence has found that high technology sectors are particularly vulnerable to cycles, as shown in Fig. 2 by the higher fluctuations of employment in science-based and specialised suppliers industries, while scale-intensive industries have a higher degree of market power that can explain the greater stability in their employment patterns over the cycle. Findings have shown that during upswings the potential for Schumpeterian profits from major innovations is greater, and this favours the introduction of new products and the expansion of new markets. On the other hand, in industries where innovations are less important, the expansion of demand lowers the competitive pressure and the need to innovate; during upswings even less-efficient firms may survive and profit. Conversely, during downswings, the lack of demand may discourage the introduction of new products and may increase competition based on costs and prices, leading industries to focus on new processes that lead to labour-saving and cost-cutting in the context of restructuring and exit of less-efficient firms. During upswings aggregate industry growth, as well as productivity increases, appears to be supported by both new products and new processes, as both technological and cost competitiveness may lead to output or efficiency improvements. During downswings new processes associated with restructuring appear relevant in containing the fall in economic activities, while new products and demand lose their importance (Lucchese and Pianta 2012; Cirillo et al. 2018).

The structural effects of slumps should not be ignored; recessions disrupt the mechanisms of innovation-based growth and push firms towards a technological trajectory based on labour-saving new processes that increase efficiency but destroy jobs. Along with jobs, competences, skills and production capacity are lost during recessions, with the risk of setting the trajectory of growth on a lower path of development.

(9) The impact of technology is different across occupations and skills

Stylised fact 9 breaks down total employment into different *qualities* of jobs, defined by skills, tasks and occupations. Within the mainstream, studies on *skill biased technological change* have focused on the complementarity between technologies and skills, predicting an increasing importance of skilled workers (Berman et al. 1994; Autor et al. 1998; Chennels and Van Reenen 1999; Acemoglu 2002, Acemoglu and Autor 2011). A 'race' was also expected between the increasing demand for high skills due to the introduction of technologies and the supply of skills in the labour market (Goldin and Katz 2008).

In fact, what is emerging in most countries and industries is a more polarised employment structure, that is documented by the nature of 'tasks' performed (*routine biased technical change*) distinguishing between routine jobs—both cognitive and manual (such as those of clerks and factory workers)—that are easier to replace with computers, and non-routine activities (such as those of those of managers and gardeners) (Autor et al. 2003; Autor and Dorn 2013; Goos and Manning 2007; Goos et al. 2014). Routinisation has a strong effect on job changes; the effects of technology on skills are often mixed with those of foreign trade. In the case of US industries in the 1990s, the job destroying impact of innovation appeared to be dominant, while international trade played a minor role (Berman et al. 1998).

The impact of the Great Recession on jobs in the USA has been recently investigated by a set of studies edited by Card and Mas (2016); weak demand

Table 1 Occupational groups and educational level

Occupational groups	ISCO 1 digit classes	Educational level (ISCED)
Managers	Managers, senior officials and legislators	3+4
	Professionals	4
	Technicians and associate professionals	3
Clerks	Clerks	2
	Service and sales workers	2
Craft workers	Skilled agricultural and fishery workers	2
	Craft and related trade workers	2
Manual workers	Plant and machine operators and assemblers	2
	Elementary occupations	1

dynamics, the lack of hiring by small firms, the role of imports from China were identified among the factors contributing to slow employment growth in the USA. Considering the skill structure of US jobs, Beaudry, Green and Sand (2016) suggest a deskilling pattern in the occupational structure due to a contraction in the demand for skilled workers performing cognitive tasks, leading to a stagnation in their wages. Such trends—they argue—have been accelerated by the collapse of the US housing bubble. Therefore, high-skilled workers moved down the occupational ladder and displaced lower-educated workers in less skill-intensive jobs, suggesting a deskilling pattern in the occupational structure.

More solid and systematic evidence may come from data based on the International Standard Classification of Occupations (ISCO) that could be organised in four main groups: managers, clerks, craft and manual workers (see Table 1); these occupational groups are able to account for the employment hierarchies both in terms of education attainments and wages (Cirillo et al. 2018).

Figure 4 above provides an overview—for the five largest EU economies—of the patterns of change of the four professional groups in the years before and after the crisis. During the upswing from 2002 to 2007 employment growth has not reflected a general upskilling of jobs, but rather a polarising pattern has emerged, with expanding jobs for managers and for the lowest skilled manual workers, while mid-level skills for both white collars (clerks) and blue collars (craft workers) declined. This polarising pattern is particularly evident in services. The picture is different after the start of the crisis; a major destruction of blue collar jobs has taken place, with managers only increasing the number of jobs. Craft workers have a worse dynamics than manual workers, reflecting the expansion of ancillary jobs in low qualified activities (Eurofound 2013) that is a key element of the pattern of polarisation. Growth in managers is stronger in Spain, Italy and France—where catching up effects in the skill structure could be relevant—while increases in manual workers are found in Germany, Spain and Italy.

Data for 38 manufacturing and service industries in five major European countries highlight the connection between nature of innovation and occupational group

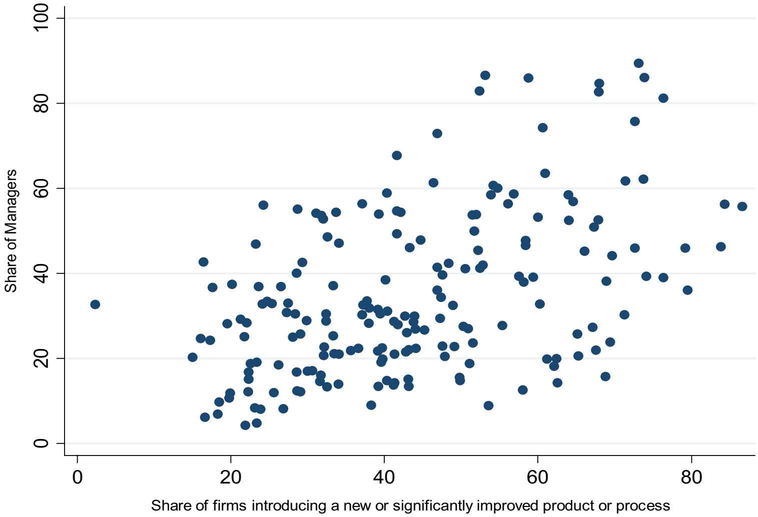

Fig. 5 Innovation in firms and shares of managers in employment. Averages 1999–2011, five European countries, 38 manufacturing and service industries, percentages. *Source*: Cirillo et al. 2018

(see Cirillo et al. 2018). Figure 5 shows that the share of managers in total employment is positively associated with the share of firms introducing an innovation (either new product or new process), with a wide dispersion due to industry and country diversity. Figure 6 highlights the negative association between the share of manual workers and that of firms introducing an innovation. Industries with greater innovative potential are characterised by higher skills, while those where manual workers constitute the bulk of the workforce have the lowest technological activities.

Empirical investigations have shown that each occupational group is differently affected by innovation and other factors of change. Managers are the group that is most favoured by the introduction of product innovations, while process innovations negatively affect the jobs of low skill workers. It has also been shown that the impact of offshoring is parallel to the one of process innovation, with negative effects especially for low skill workers. If we investigate the different effects during the business cycle, we find that the gains in the expansion are concentrated in managers, while in the recession the largest losses hit craft and manual workers (Cirillo 2016a, b; Cirillo et al. 2018). These findings suggest that standard relationships between innovation and jobs are disrupted during downswings (Card and Mas 2016).

The hierarchical position of different occupational groups is not irrelevant for understanding decisions on innovation; this may contribute to explain the ability of stronger occupational groups (managers) to benefit from new product technology and preserve their jobs even during recessions; conversely, the weaker professional groups (manual workers in particular) have been hardest hit by job losses associated with new processes and to the restructuring taking place during recessions. These different outcomes are the result of how different professional groups are able to control decisions in firms, shape the type of technological

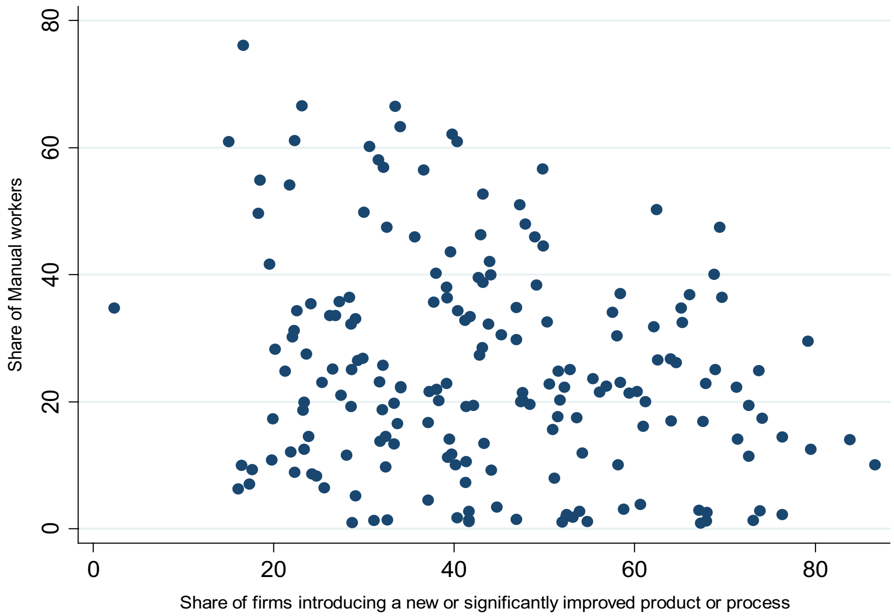

Fig. 6 Innovation in firms and shares of manual workers in employment. Averages 1999–2011, five European countries, 38 manufacturing and service industries, percentages. *Source*: Cirillo et al. 2018

change that is introduced, and protect themselves from potential threats in markets and technology, building on their bargaining and contractual position.

(10) Labour market conditions are relevant, but employment outcomes are not determined in labour markets alone

Stylised fact 10 brings us to the labour market, where the number of jobs and wage levels are determined. For mainstream economic approaches this is the most important context for assessing the employment impact of technology. For the alternative approaches investigated above in this paper, the key mechanisms shaping the innovation–employment nexus are operating well before the labour market stage—in the dynamics of technology and in the product market where labour demand takes shape.

In the labour market, in fact, equilibrium is found simply moving along a given labour demand curve, encouraging at the same time a greater supply of labour, typically through education and 'active labour market policies'. Mainstream views emphasise the need for efficient and flexible labour markets as a tool for addressing unemployment, reducing union power, collective bargaining agreements, employment protection and minimum wage regulations. The US labour market is often portrayed as a model of efficient operation, and in the past decade many European countries have moved in such a direction introducing labour 'reform' packages. In this perspective employment dynamics is expected to be driven by wage levels; business cycles have a role here as workers and unions reduce their wage claims in periods of high unemployment (Pissarides 2009; a discussion of wages is in Stylised fact 12 below).

Technology factors are largely neglected by these approaches; besides wage levels, mainstream views and policies have targeted 'excessive' regulations and rigidities as the culprit of the imperfect working of the labour market; a large attention has gone to the types of employment contracts (open ended or temporary; full or part time), hiring and firing restrictions, the presence of labour rights, unions' bargaining power, welfare conditions, etc., as factors that could prevent a more 'efficient' operation of labour markets. In most advanced countries policies have gone in this direction, leading to the decline of standard employment—full time, permanent jobs with union contracts, employment protection, social insurance and pension systems. The 2015 International Labour Office report has documented the rise of non-standard jobs and has showed that 'over 6 out of 10 wage and salaried workers worldwide are in either part-time or temporary forms of wage and salaried employment. Women are disproportionately represented among those in temporary and part-time forms of wage and salaried employment' (ILO, 2015, p. 13).

In the alternative approaches for understanding the innovation–employment nexus discussed above, labour markets do play a role, but attention goes to the segmentation of labour supply and demand on the basis of education and skills; on appropriate education, learning and training activities; on the way workers' learning may support continuous innovation in firms; on employment contracts and their impact on technological activities; on the appropriate welfare protections that may reduce exposure to social risks and encourage innovation; on the way wages can capture a fair share of the productivity gains made possible by technological change (see Stylised fact 12). In fact technological change—as a process shaped by social relations (Stylised fact 1)—responds to the social and institutional constraints that emerge in a society; labour market conditions, rules on working time, labour rights and social protections are fundamental aspects of the way human labour interacts with particular technologies.

(11) In emerging countries employment outcomes are jointly affected by technology and catching up

Stylised fact 11 addresses the specific conditions of emerging countries. The ability to introduce new technologies is now seen in developing economies as a crucial element in the process of industrialisation. Major efforts to introduce new products and processes, to imitate rapidly frontier innovators, to widely adopt new capital equipment and production technologies, to diffuse the use of new goods and services are now under way in many developing and emerging economies, from Eastern Europe to China, from India to South-East Asia, from Latin America to Southern Africa. This process is highlighted by the success of some Asian countries (most recently China and India) in shifting from a paradigm of technology adoption to one of domestic knowledge generation (Chadha 2009; Altenburg et al. 2008), although the ability of other countries to follow the same road has been questioned (Sargent and Matthews 2008; Perez 2008).

Such attention to technology has led to a rapid diffusion in these countries of innovation surveys, replicating and adapting the model first developed in Europe (OECD 2005; Eurostat 2008; Blankley et al. 2006). The advantage of innovation surveys is in their ability to document the complex and multidimensional nature of technological change in firms (Dosi 1982; Pavitt 1984), offering a variety of indicators on inputs, outputs, sources, objectives and hampering factors.

A detailed investigation has reviewed and compared the evidence from innovation surveys in emerging countries referring to the time period between 2002 and 2006 (Bogliacino et al. 2011). A summary of the main findings is provided below. Table 2 shows that in general EU-15 outperforms emerging countries in terms of innovative output, but the variance among the latter is very large. There are a few Asian countries—such as South Korea—whose performances are comparable or higher than the EU-15. Most emerging countries and countries or recent accession to the EU have innovative output that is moderately behind EU-15 levels. A few countries lag behind the EU by a substantial margin—such as Russia, Ukraine and Thailand. It should be pointed out here that data on innovative turnover refer to the share of sales of products that are new to the firm, including therefore both innovation and imitation; for example, Malaysia has a 42% share on innovative turnover, but the percentage which does not result from imitation is about 14%.

Figure 7 shows the trade-off between the two major priorities in the expenditure on innovation—on the one hand, the prevalence of R&D, typical of countries closer to the technological frontier and engaging in original innovation; on the other hand, the concentration of resources on the introduction of new production technologies (usually developed elsewhere) through the acquisition of new machinery and equipment. Countries in the process of industrialisation tend to devote the large majority of their technological efforts to the latter; this is the case of Latin America (with the exception of Brazil), Russia, South Africa, but also of the Central and Eastern European countries that have recently joined the EU. On the other hand, China, other Asian countries and Turkey have an intermediate position, devoting their efforts in roughly equal shares to R&D and new machinery; this shows that such countries are moving closer, at least in some sectors, to the European pattern of expenditure for innovation.

Table 3 shows the main objectives of innovation; strategies based on new and improved products may be linked to a search for new markets and a wider product range, while efforts focused on production processes may lead to greater capacity and flexibility, or lower labour and other production costs (again, data do not add up to 100 as they show the share of firms indicating each objective as relevant). Quality improvement appears as the dominant objective in emerging countries, associated with other product-related efforts; in parallel, innovation in processes aims at strengthening the productive capacity—especially in Asia and Latin America—with concerns on labour costs playing a more limited role.

In the evidence above a systematic comparison between manufacturing and service industries has been provided. Results are generally consistent across different

Table 2 Innovative output

Countries	Manuf. or serv.	Share of innovative firms	Product and process (as share of innovative firms)	Product only (as share of innovative firms)	Process only (as share of innovative firms)	Share of turnover due to new, improved products
EU 15	M	48.9	45.2	21.3	27.7	10.4
	S	41.5	41.7	22.7	30.7	6.3
EU NMS	M	30.7	48.2	22.0	24.9	11.5
	S	23.8	42.0	23.0	28.1	11.1
Russia	M	9.3				10.6
	S	15.3				3.1
Ukraine	M	11.5				6.7
Turkey	M	35.3		25.1	25.0	
	S	24.6		16.7	18.5	
China	M	30.0	21.3	3.8	4.8	14.4
South Korea	M	42.0	18	18	5	54
	S	21.0				
Malaysia	M	53.8		10.6	6.2	42*
Thailand	M	6.4		4.10	4.3	
	S	4.0				
Taiwan	M	39.6		27.6	27.2	
	S	32.4		23.2	20.4	
Singapore	M	31.7		24.1	22.4	29
	KIBS	56.9		44.4	49.4	
South Africa	M	54.8	38.4	11.1	3.5	13.7
	S	49.3	22.9	12.7	7.3	7.6
Argentina	M	41.7				
Brazil	M	33.3				38.7

Table 2 (continued)

Countries	Manuf. or serv.	Share of innovative firms	Product and process (as share of innovative firms)	Product only (as share of innovative firms)	Process only (as share of innovative firms)	Share of turnover due to new, improved products
	S	51.7				50.4
Colombia	M	33.4				
Chile	M, S	37.9				24.9

M Manufacture, *S* services, *KIBS* refers to knowledge intensive business services. In column (2) the unit is the share of total firms, in column (3)–(5) the share of innovative firms, and in the final column the share of total turnover

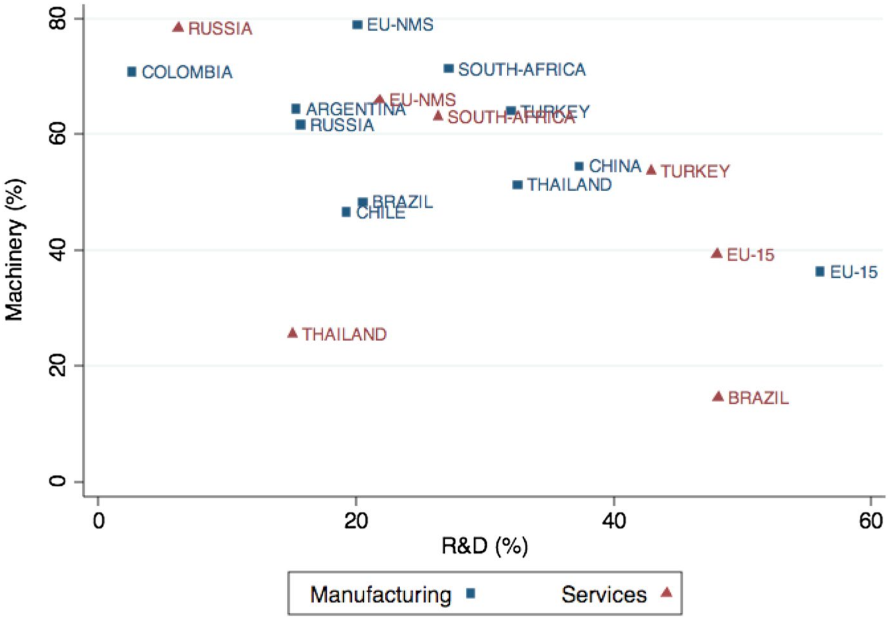

Fig. 7 R&D and acquisition of new machinery in selected countries. Data are expressed as share of total innovation expenditure

variables; innovative efforts and outputs tend to be stronger in manufacturing, with services following closely in most countries.

Combining this empirical evidence (Bogliacino et al. 2011) and key insights from the existing literature—in particular Abramovitz (1986), Lall and Pietrobelli (2002), Freeman and Louçã (2001), Perez (2002)—the following patterns can be identified.

In emerging countries technological change mainly takes the form of acquisition of new machinery and imitation of the products and processes developed elsewhere. Both technology adoption and imitation can spread rapidly among firms in emerging countries, with the benefits typical of catching-up processes.

Innovation, however, requires resources and institutions; in emerging countries the gaps are not simply of a quantitative nature—the amount of R&D, of higher education, of high technology investment—but concern the nature of the national system of innovation, with a frequent lack of integration between firms in the production system, the financial sector, research and education activities and the policies of the public sector. The evidence on the sources of knowledge and obstacles to innovation points out the importance of building a coherent innovation system.

Innovation is pushed by industrialisation and pulled by growth of markets. On the supply side, the dominance of new machinery among innovative expenditures and the importance of technology adoption suggest a close link to the process of industrialisation. On the demand side, countries integrated in international production networks are able to diffuse modern production competences adopting new process

Table 3 The objectives of innovation

Countries	Man. or serv.	Quality improvement	Range of products	New markets	Productive capacity	Flexibility	Labour cost	Other cost
EU 15	M	37.5	33.0	28.5	26.6	26.9	20.4	12.3
	S							
EU NMS	M	32.2	30.0	24.9	25.9	22.7	13.3	11.9
	S							
Russia	M	34.0	40.5	21.3	17.7	15.2	3.7	7.2
	S	55.9	50.3	15.0	27.1	25.8	2.9	5.6
Ukraine	M							
Turkey	M	83.4	76.8	74.2	79.4	78.4	68.1	55.0
	S	82.1	70.0	77.0	77.4	76.5	54.3	42.3
China	M	49.2	45.2	47.3	47.3	32.5	31.9	37.5
South Korea	M	63.0	46.0	52.0	45.3	43.0		
	S	41.5	32.8	25.0		17.5	24.2	25.0
Malaysia	M							
Thailand	M							
	S							
Taiwan	M							
	S							
Singapore	M	48.3	44.6	29.9	16.0	16.1	14.4	13.3
	KIBS	43.6	25.1	17.8	22.0	14.5	2.2	2.2
South Africa	M	48.3	44.6	29.9	16.0	16.1	14.4	13.3
	S	43.6	25.1	17.8	22.0	14.5	2.2	2.2
Argentina	M							
Brazil	M	68.4	42.0	28.1	58.0	48.3	38.5	39.7
	S	82.5	69.3	46.3	66.4	62.3	35.3	33.8
Colombia	M	53.4	26.5	31.7	46.3	25.5	24.4	24.0
Chile	M/S	51.8		60.1	59.1	59.1		59.1

M Manufacture, *S* services, *KIBS* refers to knowledge intensive business services. Data are expressed as shares of innovative firms

technologies, finding expanding markets for products that imitate those of advanced countries.

Being exposed to international competition favours innovation. When facing external competition, firms tend to adopt technology faster, a result that has emerged also in advanced countries. However, this does not mean that developing economies automatically benefit from opening up to trade and foreign competition in all industries; where domestic capabilities are inadequate and dynamic scale economies are not yet reached, opening up may simply put domestic firms out of business, losing part of the production system. The search for a trade-off between these opportunities and risks is a matter that should be addressed by national industrial policies (Cimoli et al. 2009).

The affiliates of multinational corporations tend to be more innovative than the national average, another result that has also emerged in advanced countries (Castellani and Zanfei 2006). This is linked to intra-firm knowledge flows and to the strategies by foreign firms aiming to exploit their competences and technologies in local markets. However, little domestic technological capabilities may be produced, the integration between foreign affiliates and local firms can be modest, and the spillover effects in terms of knowledge, competences and productivity can be small.

The main obstacle to innovation is its economic cost and the lack of finance, again a result also found in advanced countries. In emerging economies the absence of advanced and forward-looking financial systems is a major weakness of national innovation systems.

Building on this empirical evidence, a typology of four trajectories linking innovation, development and employment could be proposed.

(a) *Technological dependency* is typical of countries with a small industrial base, where the main part of the economy is made up by agriculture or export commodities. Technology—in different forms—is generally acquired from abroad. The lack of a knowledge infrastructures prevents the exploitation of foreign technology that remains difficult to adopt and imitate. The actual effects on productivity and employment may be uncertain.

(b) *Imported technological capabilities* are found when there is significant acquisition of foreign technologies by domestic firms through new machinery and learning processes, leading to new productions, but with no inventive capabilities. This pattern may be typical of economies that are resource-intensive, commodity-exporting or at the first stages of offshore production; they tend to be unable to build a critical mass of domestic knowledge base. The acquisition of machinery may allow some catching up in productivity levels; however, alongside machinery they may import the same labour-saving bias typical of advanced countries in very different employment contexts.

(c) *Integration in international technology networks* is the pattern typical of open economies with close links between foreign-owned domestic firms and the system of international production of multinational firms. We can find here transfer of technologies, growing production capabilities and participation to innovative activities, mainly through the acquisition of new machinery. This may lead to positive innovative performances, but with a limited consolidation of the domestic knowledge base. The employment impact is driven here by export demand which could require large job creation. However, key decision on the types of technologies used may remain in the hands of the multinational firms controlling international production, leading to very different (and unstable) innovation–employment relationships. Recent evidence includes cases—such as those of Foxconn and Nike—of advanced robotisation strategies that may replicate in emerging countries the massive labour-displacing effects of advanced economies.

(d) *Independent technological capabilities* is a trajectory characterised by the development of internal innovative capabilities and activities by domestic firms (ranging from R&D to design, imitation and adaptation of foreign know-how),

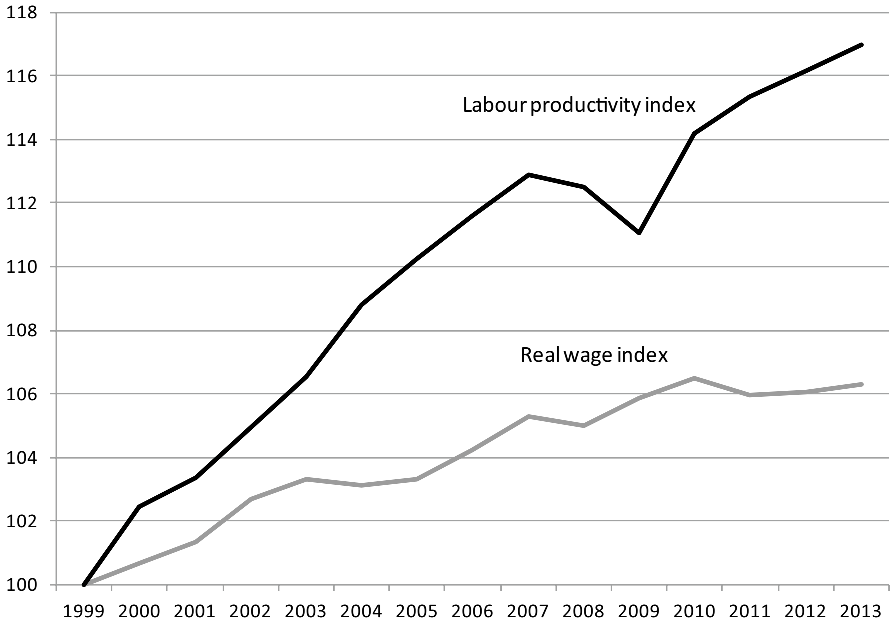

Fig. 8 Growth of labour productivity and average wages in advanced countries, 1991–2013. Wage growth is calculated as a weighted average of year-on-year growth in average monthly real wages in 36 economies. Index is based to 1999 because of data availability. Data from ILO Global Wage Database; ILO Trends Econometric Model. From: ILO (2014), Global Wage Report 2014/15, p.8. © 2015 International Labour Organization

leading to new productions for the internal and international markets, and the ability to compete with advanced countries at least in some product groups and industries. This is the condition of the largest emerging countries that face the challenge to extend and diversify their technological activities. The employment impact of such trajectory includes the job creation effects of new products in areas of national strength and is moving closer to the pattern discussed in the case of advanced countries.

Elements of these different trajectories may coexist in different industries of emerging countries, with a complex interaction between technology, development patterns and job creation. However, for emerging economies the employment impact of technology may appear to be more problematic than in advanced countries; structural problems are likely to be more serious, and the compensation mechanisms could be less effective (Karaomerlioglu and Ansal 2000). The diffusion of automation is also creating new challenges for emerging countries (World Bank 2017).

(12) Technology is an engine of inequality; profits benefit more than wages, wage disparities increase

Stylised fact 12 concerns the distribution of the benefits of innovation between capital and labour and among workers. There is ample evidence that the current patterns of technological change have contributed to the unprecedented rise in income inequalities in most advanced countries (Franzini and Pianta 2016; Piketty 2013).

An effective way of documenting the loss of labour and the gains of capital as a result of technological change is provided by Fig. 8, drawn from the ILO Global wage report, showing productivity and wage dynamics in the 36 largest economies since 1991. Innovation is a main driver of productivity gains; productivity growth has not been particularly rapid, with average increases around 1.2% per year, but wage increases have been left behind and are basically flat since 2009, with average increases around 0.4%. Wage increases equal to productivity growth are generally required if we want to maintain a stable distribution of income between wages and profits. The effect of technology on income distribution between profits and wages, and on disparities among workers is examined below.

Disparities between profits and wages In advanced countries over the last decades the functional distribution of income between labour and capital has seen a shift of 10–15 percentage points of national income from wages to profits, resulting in a major increase in inequality. Real wages have fallen for a large number of workers. The 2012 OECD Employment Outlook argued that the reduction in the labour share was linked to labour-displacing technological change, to a rise in domestic and foreign competition—including delocalisation and imports that replace national production—and to the reduction of public ownership through privatisations (OECD 2012, p. 111).

An investigation on the dynamics of profits and wages in manufacturing industries, covering ten European countries in the period 1994–2001 (Pianta and Tancioni 2008), has shown that the real growth of wages per employee was less than half that of total profits. In high innovation sectors, profits increased by close to 8 per cent a year, three time as fast as wages. In low innovation industries profits growth was 3.5 per cent, again more than twice that of wages. While increases in labour productivity are the source of increased remuneration for both capital and labour, the conflict over distribution is a strong factor in explaining the relative gains of profits. Wages tend to grow faster in the sectors where innovation expenditure (largely due to wages for high skill researchers) is higher, while profits are driven both by the importance of new products and market power, and by restructuring through the diffusion of new processes and wage depressing job reductions. The lesson of such evidence is that technological change has the general effect of favouring profits over wages. Profits increase through separate mechanisms in industries relying on technological or cost competitiveness; conversely, wages grow only when innovation is associated with higher skills of labour; the result is greater inequality rooted in the functional distribution of income (ibid.).

Disparities among wages Wage inequality has significantly increased. A preliminary clarification concerns the remuneration of top managers that is often classified as 'wage' but in fact is part of the distribution of a firm's profits. Even once we eliminate the rapidly growing compensations of top managers, disparities among wages are relevant along many dimensions.

Across educational levels and skills, wages tend to be higher and grow faster for workers with higher education, higher skills or using computers at work (for reviews see Chennells and Van Reenen 1999; Acemoglu 2002).

Across industries we generally find that advanced services and high innovation manufacturing industries have higher wage levels and faster wage increases, even in the countries with a weaker technological dynamism. Conversely, low innovation industries tend to have a modest wage dynamics, with a wide spectrum of variation; these patterns clearly result in growing wage polarisation (Pianta 2004; Galbraith 2012).

Innovative strategies also emerge as important factors. A study at the industry level, covering ten manufacturing and service sectors in seven European countries (Croci Angelini et al. 2009), has found that a higher wage polarisation is found in industries with strong product innovation, a fast employment dynamics and high shares of workers with university education; sectors with greater opportunities for expanding markets and jobs are likely to show increasing wage inequalities, as managers and high skill workers can obtain part of the rents from innovation. Conversely, wage compression is typical of industries characterised by the diffusion of new process technologies, high shares of workers with secondary education who can increase their competences and productivity by working on new machinery, obtaining higher relative wages (usually in a context of relatively high unionisation and labour market regulation), leading to reduced wage disparities.

Again, the effects of technology on wages are often combined with those of foreign outsourcing resulting in a stronger downward pressure on wages of low skilled workers (Feenstra and Hanson 1996, 2003; Bogliacino et al. 2016).

However, the relationship between innovation and wages may also run in the opposite direction; low wages, precarious work and high labour market flexibility can eliminate a major incentive for introducing innovation in firms, resulting in worse technological performances (Kleinknecht 1998; Cetrulo et al. 2017).

Labour market institutions also play a major role in the rise of wage disparities. In the last three decades all major international organisations—such as the OECD and the IMF—have asked governments to introduce labour market 'reforms' going in the direction of more flexibility, lower employment protection and union power, based on the mainstream argument discussed in Stylised fact 10 that more flexible labour markets help reduce unemployment. Such policies have been introduced in a large number of countries, resulting in high wage disparities. A surprising reversal in policy advice has now emerged. The last OECD report on inequality (OECD 2015) emphasises the responsibility of weaker labour market institutions in the rise of wage inequality. The report acknowledges that 'declining union coverage had a disequalising effect on the wage distribution' and that 'high union density and bargaining coverage, and the centralisation/co-ordination of wage bargaining tend to go hand in hand with lower overall wage inequality in both OECD countries and emerging economies' (OECD 2015, p. 42; see also OECD 2011). A specific attention is devoted to the rise of non-standard jobs that 'can also be associated with precariousness and poorer labour conditions', lacking 'employment protection, safeguards and fringe benefits enjoyed by colleagues on standard work contracts'; the consequences are that 'a non-standard job typically pays less than traditional permanent work (…).

These earning gaps are especially wide among low-skill, low-paid workers: non-standard workers in the bottom 40% of earners typically suffer wage penalties of 20% (…). Non-standard workers also face higher levels of insecurity in terms of the probability of job loss and unemployment and, in the case of temporary workers, report significantly higher job strain' (ibid. p. 31). The OECD now advocates a minimum wage that 'can help supporting low-wage workers and low-income families while avoiding significant job losses' (ibid., p. 42).

A similar argument has been made by the IMF in a study (Dabla-Norris et al. 2015) showing that a decline in organised labour institutions is associated with higher inequality measured by Gini coefficients, 'likely reflecting the fact that labor market flexibility benefits the rich and reduces the bargaining power of lower-income workers'. Additional evidence shows that 'more lax hiring and firing regulations, lower minimum wages relative to the median wage, and less prevalent collective bargaining and trade unions are associated to higher market inequality' (Dabla-Norris et al. 2015, p. 26).

The above evidence suggests the need for policies addressing the distribution of the productivity gains resulting from technological change. Over the past decades, innovation has mainly benefited capital in the form of higher profits, top earnings and financial rents in a context of increasing pressure on firms from investors demanding high financial returns. Conversely, technological change has often hit workers with job losses associated with labour-saving new processes, with new forms of low wage precarious work, with stagnant real wages. Technology is one of the engines of income inequality that has now reached record levels in many advanced and emerging countries. Such disparities are not only a problem of social justice, and they also undermine the possibility of growth and efficiency—as argued also by the OECD: 'when income inequality rises, economic growth falls' (OECD 2015, p. 60). New policies are therefore required for changing this state of affairs, for shaping technological change in the interest of society; for reducing its negative employment effects; for making sure that the gains from innovation and productivity go to labour in the forms of higher wages, lower working hours and improved working conditions.

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