Current Perspectives on the Employment Impact of Digital Technologies (*)

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Abstract: This paper examines the ongoing debate about whether digital innovations are an opportunity or a risk for employment in advanced economies. The main frameworks of analysis and the stylised fact of the employment effect of technological progress are explained before presenting the most recent empirical insights on the relationship between digital innovations, productivity growth and employment growth. Finally, the impact of digital technologies is examined for varying types of skill composition of labour and the implications in terms of unemployment and income inequalities are raised. The paper offers a review of the literature on the topic.

Key words: Digital technologies, employment, job polarisation, productivity, skill-biased technological change.

The accumulation of digital capital drives aggregate productivity growth. A capital-labour substitution occurs in the early phase of technology adoption, causing a short-run trade-off between productivity and employment, while in the long run aggregate productivity growth is in general associated with employment growth. Recent decoupling of labour productivity and employment in the U.S., along with the decline of the share of labour compensation in aggregate income of OECD countries, could suggest that digital capital adoption will continue to drive productivity while employment growth could slow down. This would occur through a process of increasing capital-labour substitution whereby the amount of capital relative to labour increases and the returns to capital accumulation relative to labour increase, thus driving a rise of the proportion

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of gross output that is accounted for by capital. In addition, there is concern that a slowdown in productivity growth potentially linked to lower contribution from digital capital might hinder the potential for employment creation within OECD economies. On the other hand, a renewed cycle of productivity fuelled by new generations of digital technologies could reproduce the U.S. productivity resurgence of the 1995-2000 period and lead to a decline in unemployment. Whether productivity will increase above its long-run average is uncertain, however. A return to a period of high labour productivity would normally raise demand for labour – in particular highly-skilled labour – through a process of skill-biased technological change.

Recent studies suggest that over the past thirty years, information and communication technologies (ICTs) [1] may have contributed to a process of polarisation of employment in Western countries. In this process, a large number of middle-skilled workers performing routine tasks in services industries have been replaced by digital capital, while demand for high-skilled and low-skilled labour has either increased or stagnated. Other studies expect new generations of digital innovations to hamper employment by further displacing medium-skilled jobs, and also abstract, non-routine tasks. On the contrary, another recent study argues that ICTs only displace low-skilled routine tasks. From this perspective, post-2000 decline in U.S. employment growth is considered to be the result of macroeconomic shocks rather than of polarisation and skilled-biased digital technologies.

Recent empirical results, however, suggest that the hollowing-out of middle-skilled U.S. jobs explains the jobless recoveries of the last thirty years. From this perspective, employment does not rebound after recessions because middle-skilled routine employment, which accounts for a large share of aggregate employment, is disappearing. In addition to the decline in the share of labour compensation which might partly be driven by ICT, there is reasonable evidence that future productivity growth might not always be associated with stronger employment growth. Most literature in the area suggests that the optimal policy to tackle potential detrimental economic effects of digital technologies is to promote digital skills in order to reduce inequalities and concentration of wealth resulting from both skilled-biased technologies and capital-augmenting technologies. A broader diffusion of skills in the workforce increases labour complementarity with digital capital and also benefits employment during technology adoption.

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[1] ICTs are also referred to as "Digital technologies", and ICT capital is also referred to as Digital capital, mainly in the recent literature.

Digital technologies and employment in the research debate

The relationship between digital technologies and employment is a matter of debate and controversy. The economic effects of digital capital adoption in the production system have been widely researched since the early 1990s, with a focus on the effects of ICT investment on labour and multifactor productivity growth. Investment in ICT has been a major source of productivity and output growth in OECD economies over the last two decades. The contribution of ICT capital to output growth has been particularly highlighted by COLECCHIA & SCHREYER (2001) and CETTE *et al.* (2010) who have underlined the contribution of ICT capital deepening to labour productivity growth in OECD countries.

Yet the assessment of employment effects of digitisation has not led to general unambiguous results in the economic literature. SABADASH (2013) observes that the number of empirical studies that specifically focus on ICTs is limited compared to the general literature on technology and employment. She concludes that despite a wealth of theoretical models and empirical evidence, a consensus regarding the employment effect of ICTs remains elusive. This conclusion stems notably from the difficulty to account for the large variety of channels through which ICTs influence labour markets, and the difficulty to capture the impact of fast-changing nature of digital technologies on labour and skills demand. The OECD (2014) also underlines that "the net impact of the internet on jobs is unclear and more work is needed to understand the phenomenon".

The employment effect of ICT depends on capital-labour substitution and demand for skilled labour

While the net impact of digital innovations on employment remains ambiguous, some effects of ICT capital accumulation on labour input are well-established in the literature. According to SABADASH (2013), two main frameworks are used to assess employment effects of ICTs. The first is the neo-classical "compensation framework", whereby the initial labour-saving effect of technological progress (increase in capital-labour ratio or capital deepening) is compensated for through lower input factor prices due to productivity growth, that in turn translates into lower prices followed by an increase in consumer demand. Firms thus raise demand for labour to meet increased consumer demand, which also results from the marketing of new products and equipment.

The second framework is the "substitution framework", whereby labour-saving effect (substitution of capital for labour) leads to employment displacements. The adoption of digital technologies raises high-skilled labour productivity. Therefore it raises high-skilled labour demand vis-à-vis unskilled labour, through a skill-biased technological change, as described by ACEMOGLU (2002). In addition, the labour market polarisation effect examined by ACEMOGLU & AUTOR (2011) and AUTOR & DORN (2013) means that digital capital lowers demand for routine and repeated tasks that are generally performed by medium-skilled, medium-wage workers. Demand is maintained, however, for low-skilled manual tasks that have shifted from manufacturing to services industries. Digital adoption has thus increased the proportion of employment of high and low-skilled workers, and decreased the proportion of employment of the middle-skilled in Western countries over the last three decades [2].

According to the OECD (2014), the adoption of "internet-based technology" leads to the creation of new types of occupations and additional employment in existing sectors, raises demand for high-skilled specialised workers, supports international jobs reallocation through outsourcing, and also suppresses employment through the replacement of labour by digital capital. However, "the combined effect of these drivers is not obvious, and may depend on specific conditions and policies in each country". No unambiguous overall net employment effect of digital capital adoption has been clearly shown in existing literature. Some recent studies, however, provide insights on expected employment outcomes of the current wave of digital innovations.

The macroeconomic perspective: the link between digital capital, productivity and employment growth

There is worldwide historical evidence that productivity growth is not detrimental to employment growth in the long-run, while technology-induced

[2] A study from CEDEFOP (2011) concludes that labour market polarisation emerged in Europe between 1998 and 2008 mainly as a result of the macroeconomic cycle and structural changes in industries, with only a minor role played by technological change.

productivity shocks might raise unemployment only in the short run. The adoption of digital technologies has largely contributed to productivity growth of OECD countries during 1995-2007 (SPIEZIA, 2013), and in particular to aggregate productivity in the U.S. during 1995-2000 (JORGENSON *et al.* 2007), while unemployment was decreasing sharply [3]. However, it is still unclear whether aggregate productivity will grow at a comparable pace in the future and whether productivity growth at aggregate or industry level will be associated with employment growth in the U.S. and more generally in Western countries.

Long-run trends of aggregate productivity growth are not associated with unemployment growth

VAN ARK *et al.* (2004) show that for a cross-section of 66 countries between 1980 and 2000 more than two-thirds exhibit both productivity and employment growth and "although productivity growth and employment growth tend to be weakly negatively correlated, a rise in productivity only coincides with a decline in employment in very limited number of cases". The authors acknowledge that in the medium-run a trade-off between productivity and employment growth can occur but, in general, such a trade-off is addressed and "turned into a positive relationship". In the long run, economies tend to exhibit simultaneous growth of per capita income, productivity and employment.

An MGI (2011) study shows that in the U.S. the trade-off between employment growth and productivity growth only occurs in the short run, while over a long period (1929-2009), productivity and employment do not exhibit opposing trends as "more than two-thirds of the years since 1929 have seen positive gains in both productivity and employment", while "employment growth followed gains in productivity in 71% of quarters since 1947".

ATKINSON & MILLER (2013) provide an extensive literature review of the relationship between productivity growth and employment in developed countries. They conclude that there is no statistical evidence that aggregate productivity growth is detrimental to employment. Correlations between productivity-enhancing technology shocks and unemployment are only observed in the short run. Over the medium and long run, on the other hand,

3 http://data.bls.gov/timeseries/LNU04000000?years_option=all_years&periods_option=-specific_periods&periods=Annual+Data

technological progress is associated with higher productivity and no increase in unemployment. Unemployment is unrelated to technological progress and is, in fact, correlated with decreases in aggregate output. At firm level, however, labour demand response to a productivity-enhancing technology-shock exhibits variability and changes with cost structure, flexibility of factor input prices and the type of industry. Overall, firms that exhibit productivity growth tend to have higher employment growth than firms with no productivity growth.

Moreover, the authors show evidence that in the U.S. during the 1990s productivity (driven by ICT capital deepening) was at "near all-time high levels of growth, while unemployment was at all-time lows". Since 2000 U.S. labour productivity growth slowed down while unemployment increased. Over the long run (1947-2010), the U.S. economy exhibits an inverse relationship between productivity and unemployment. As a result, ATKINSON & MILLER (2014) advocate a strong productivity policy in the U.S., based on a "coherent science and R&D policy focused on advancing key technologies", in order to raise standards of living through the exploitation of technology opportunities.

Consistent with this view, the authors urge the European Union to increase ICT adoption in order to close the productivity gap with the U.S. that emerged in 1995. They argue that many European policy makers maintain a "view that productivity [is] the enemy of job growth, even though this view has been thoroughly discredited both by history and economics". They promote widespread ICT adoption by European public and private organisations to boost productivity and subsequently income and employment creation.

COLLARD *et al.* (2008) show that the adoption of capital-intensive ICT such as ultra-broadband increases aggregate productivity, output and welfare without harming employment in the medium and long run. A calibration model of the French economy over 1980-2020 shows that technology adoption increases unemployment only in the very short run when firms substitute capital for labour. In the longer run, technology-induced productivity mitigates the "substitution effect". As "the increase in returns to capital accumulation does increase the marginal productivity of labour", labour demand rises as technology is diffused. French unemployment is not related to ICT adoption but "to bad policies, institutional changes or bad shocks that hit the French economy".

JU (2014) investigates the employment effects of ICT capital adoption at industry level for 28 OECD countries between 1981 and 2009. The results indicate that – with the exception of mid-low skill labour in manufacturing industry – there is no evidence that ICT adoption has depressed employment in the OECD countries over the last three decades.

The recent decoupling of U.S. productivity from employment and the long-run decrease across the OECD of the share of labour compensation suggest that ICTs slow down employment growth and increase income inequality

The accumulation of ICT capital decreases the prices of intermediary inputs and capital goods, thus raising productivity, which drives capital-labour substitution in the short run. Recent studies provide insights that productivity, in part driven by technology, should not decelerate in the next years while employment will barely increase. This occurs because capital continues to substitute for labour whose marginal returns and productivity do not rise relative to capital and the share of labour compensation in aggregate income will further decrease.

BRYNJOLFSSON & McAFEE (2012) highlight a divergence between labour productivity and business sector employment in the U.S. after 2000. They argue that accelerated diffusion of digital capital is a major explanatory factor for this recent "Great Decoupling" between labour productivity and employment trends. Labour productivity has continued to increase since 2000, whereas employment creation slowed continuously and even decreased after 2007, as have median wages. The gap between productivity and employment creation, as well as median household income, has widened between 2000 and 2013. Digital technologies are intermediary inputs benefiting from rapidly increasing processing capacity and exhibiting decreasing prices since the early 1980s. As a result, firms demand more technologies and less human labour, choosing to adopt such ever-improving technologies rather than hiring workers. Firms thus "prefer capital over labour" [4]. Labour productivity in the U.S. has continued to grow while less and less workers were needed to achieve the same level of output or to increase it.

[4] Andrew McAFEE provides further empirical insights on the technological contribution to the post-2000 divergence between labour productivity and employment creation in the US: http://andrewmcafee.org/2012/12/the-great-decoupling-of-the-us-economy/

KRUGMAN (2012) [5] has observed that increasing substitution between technology and labour drives the income shift from labour to capital and contributes to the decline of the share of labour compensation in U.S. gross domestic income. The OECD (2012) stresses the significant contribution of increased productivity and capital deepening to the decline in the labour income share in nearly all OECD countries over the period 1980-2010. The OECD (2012) underlines the role of technological change, which has allowed high substitution between capital and labour, in the decrease of the labour income share.

KARABARBOUNIS & NEIMAN (2014) indicate that the labour share in gross value added of the business sector has decreased significantly in 42 countries since the early 1980s and that larger labour share declines occurred in countries with larger reduction in their relative prices of investment goods. Efficiency gains in sectors producing capital-goods are mainly due to technological progress in ICTs. As a result, the long run decrease in labour share in global income stems from digital capital accumulation which drives a shift of labour towards capital at the firm level. This is consistent with the view expressed by VAN ARK *et al.* (2004) that "worldwide technological development is strongly biased towards capital".

FREY & OSBORNE (2015) find that the share of labour in GDP has decreased between 1970 and 2014 in the U.S. and 19 advanced economies. They highlight a growing gap between labour productivity and wages since 1970 in the U.S. and 1980 for 16 of the advanced economies. The authors underline that digital capital adoption has been a driver of the decoupling between labour productivity and median wage, and of the decline in the share of labour in GDP. Digital capital adoption drives capital-labour substitution that increases capital income share and increases concentration of wealth, as "substantial wealth is being created with only a few workers and, with the exception of a small fraction of highly skilled workers, wages may not rise over their lifetime".

Research findings from JU (2014), however, suggest that there is no clear evidence that ICTs have been the main driver of the decline in labour share in OECD countries over the last three decades. He concludes that ICTs have not been related to the decrease in employment induced by high substitution of capital for labour.

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5 Paul KRUGMAN explains that the widespread adoption of labour-saving technologies induces income shift from labour to capital: http://krugman.blogs.nytimes.com/2012/12/08/rise-of-the-robots/

Studies suggest that a decline of the innovation rate in ICTs in the next years could hamper both productivity growth and employment growth

Recent analyses support the view that technological progress in general and ICTs in particular might not invariably increase productivity and might be potentially detrimental to employment. For GORDON (2012), the "computer and internet revolution" delivered its main contribution to U.S. productivity growth during the late 1990s. The digital innovations produced since then are essentially "centered on entertainment and communication devices" and do not substantially boost labour productivity and standards of living. Digital innovations will continue to contribute to U.S. economic growth but at a slower pace than they did before the early 2000s. The productivity gains generated by the accumulation of digital assets in the economy will be insufficient to offset the structural macroeconomic weaknesses of the U.S. and other similar developed countries, notably rising income inequality, insufficient level of education and "factor price equalisation stemming from the interplay between globalisation and the internet". Countries far away from the technological frontier might benefit from the productivity-increasing effect of digital technologies to bridge the gap with the richest countries. Countries like the U.S. operating at the technological frontier should only expect lower growth in the long run, however, as "the pace of productivity growth in the U.S. fades out".

In addition GORDON (2013) provided evidence that multifactor productivity growth in the U.S. after 2004 has returned to the rate achieved during the post-1972 slowdown period, which indicates that "the revival of productivity growth associated with the dot.com revolution is over". This view is also shared by COWEN (2011) who considers that the main sources of productivity growth in the U.S. have already been exploited and that the pace of technological innovation is expected to decline leading to lower employment creation.

For COHEN (2015), the digital revolution will hardly sustain productivity growth, as evidenced by the steady or even declining growth rates of industrialised countries over the last three decades despite rapid and widespread ICT adoption. Furthermore digital technologies are shifting employment towards either high or low skilled tasks that cannot be replaced by software while occupations characterised by routine, repeated tasks are at risk of being replaced by technology. As a result, in a context of weak productivity growth, a continued trend of middle-skilled job displacement is likely.

Other studies expect ICT capital investment to generate further productivity gains in the next years, close to the peak in U.S. labour productivity (1995-2005), thereby fostering employment

Recent studies suggest that aggregate productivity could be fuelled by a renewed wave of ICT capital adoption. It is likely that such a productivity rise would translate into unemployment decline, as observed during the peak of ICT-induced productivity in the U.S., during the period between 1995 and 2000. For CETTE (2014), ICTs contribution to U.S. productivity growth over the next two decades is uncertain. U.S. productivity growth associated with the ICT sector has been slowing down since the early 2000s. CETTE (2014) explains that the recent U.S. productivity slowdown is a result of a decline in ICT capital investment and a decrease of ICT productive performances since the 2000s. This slowdown is likely to continue unless ICT performances increase sharply as a result of significant progress such as "the productive use, in computers, of the 3D chip", so that "U.S. productivity growth could benefit from a second ICT wave which could be as important as the first one". CETTE (2014) acknowledges that the recent decline in ICT-related productivity growth could relate to a statistical mis-measurement of technological progress.

BYRNE *et al*. (2013) show that while digital capital contribution to U.S. labour productivity growth has slowed down over the 2004-2012 period and has dropped down to its 1975-1995 contribution, digital capital still provided a significant contribution, "accounting for more than a third of labour productivity growth since 2004". Even if digital capital is not as productive as it was during "the productivity resurgence from 1995 to 2004", it could allow labour productivity to grow at about 1.8% a year in the business sector over the next ten years. This rate would be above the 2004-2012 trend (1.56% a year) but below the 1995-2004 trend (3.06% a year). BYRNE *et al.* (2013) indicate that the price series in U.S. National Accounts might have "substantially understated the decline in semiconductor prices in recent years". This implies that the actual pace of technological progress in IT could have been underestimated. If innovation in semiconductors is in fact continuing to proceed at the same pace as in previous years, the development of innovations will also continue to be spurred more rapidly, "raising the possibility of a second wave in the IT revolution". Under this "optimistic" scenario, digital capital could contribute to bring U.S. labour productivity growth to its long-run average (2.3 percent) or above. A rise in U.S. productivity above its long-run trend is a "reasonable prospect" and means that "the information technology revolution is not over".

The future trends of digital technological progress and of aggregate productivity are uncertain. Empirical observations tend to suggest that productivity might continue to grow with lower amounts of labour input. However, based on historical insights, a return of productivity growth above its long-run level should rapidly foster an increase in demand for labour, in particular highly-skilled labour.

■ The microeconomics of productivity and employment: from skilled-biased to routine-biased technologies

To refine the analysis of capital-labour substitution, it is necessary to analyse the composition of labour. Several recent contributions have analysed how digital capital can combine with different varieties of skills and tasks. The effect of digital capital adoption on labour varies according to the type of technologies and of occupations and the implications in terms of employment outcomes also vary.

Digital technologies are a typical breed of skill biased technological change: they complement the high-skills required to implement them while they substitute for low-skills, which are replaced by digital capital

BESSEN (2015a) rejects the view that digital capital adoption displaces jobs and causes unemployment, and argues that digitisation of routine tasks in the services sector that occurred during the last thirty years in the U.S. has reallocated jobs towards tasks less subject to substitution by IT technologies. Unlike employment in manufacturing industries of advanced economies, jobs in services are shifted rather than replaced by digital capital. From this perspective, digital capital adoption can raise demand for workers with new skills required for a productive use of technology and temporary unemployment might occur if workers lack those specific skills. BESSEN (2015a) shows that in the U.S. between 1982 and 2012, employment increased more rapidly in occupations that make intensive use of computers than in the overall workforce. Wages paid to workers who acquire and upgrade specific IT skills tend to be higher relative to workers who lack such skills during a period in which the median wage has stagnated in the U.S. As a result, technology generates income inequality. BESSEN (2015b) states that with the forthcoming adoption of Artificial Intelligence Software a larger share of occupations might be at risk of being displaced. The author suggests that the optimal policy response is to increase skills through learning-by-doing in order to restore and maintain complementarity of labour input with digital capital. A policy to broaden "technical knowledge" among the workforce could tackle the gap between income of high, digital skills and income of low skills.

New digital technologies might slow down employment growth, in particular in the middle of the skill spectrum, and also substitute for cognitive non-routine tasks mainly located in services industries

The new generations of digital innovations could exacerbate employment polarisation, driving a concentration of jobs at the high end and low end of the skill spectrum, while replacing the bulk of middle-skill jobs, that involve essentially routine tasks. Because of the large share of middle-skilled job in the advanced economies, some studies argue that digital capital adoption will hamper aggregate employment growth. In addition, there is a possibility that those digital innovations will extend their reach to higher-skilled, cognitive non-routine jobs, further displacing labour input.

For BRYNJOLFSSON & McAFEE (2014), innovations in Artificial Intelligence and information analytics occurring in the "Second Machine Age" will substitute for labour in decision-making process and complex cognitive tasks. Digital technological change is biased towards skills related to "abstract and data-driven reasoning", which "increases the value of people with the right engineering, creative, or design skills". During the "First Machine Age", the 19th century Industrial Revolution, technologies increased labour productivity while humans controlled production. In the "Second Machine Age" of digital innovations, labour and technology are increasingly substitutes. New generations of digital technologies are able to substitute for cognitive and non-routine tasks which account for a large share of U.S. aggregate employment. This in turn raises demand for very high-skilled occupations which only account for a small share of aggregate employment. Overall, this leads to a decline in aggregate employment of U.S. and advanced economies unless policies are adopted to invest in human capital to restore the complementarity of labour and technology inputs.

LEVY & MURNANE (2012) share the view that digital capital adoption increases the economic value of complex problem-solving and information analytics skills relative to explicit rule-based tasks performed by middle-skilled, middle-wage individuals. The authors predict that employment at the middle of the skill spectrum will be replaced by digital capital while the demand for high-skills is expected to rise sharply relative to middle-skills.

A Roland Berger (2014) prospective analysis of the French labour market indicates that 42% of occupations are at risk of automatization due to digitisation of the workplace since 2000. The study finds that three million jobs could disappear by 2025 notably in services sectors. Alongside low-skilled, low-wage jobs in manufacturing and services sectors, intermediary jobs in services sectors are likely to be replaced by digital innovations such as data analytics (Big data and cloud computing), machine-to-machine applications, and advanced robotics. In the service sector, medium-skilled and high-skilled jobs based on repetitive tasks are at risk of automatization. Digital capital may, in particular, offer a substitute for jobs in business administration and management, legal and insurance services. The authors expect decision-making activities and activities requiring "creativity and social intelligence", in either low or high-skilled occupations, to benefit from digital capital adoption. This will lead to a growing gap between occupations likely to be automatized and those complementary to capital for which labour demand is expected to increase.

Digital technologies might not displace middle-skilled jobs, so post-2000 decline in U.S. employment growth is due to macroeconomic shocks rather than skilled-biased digital technologies

AUTOR (2014) believes that a new wave of digital technologies will not significantly displace middle-skilled occupations in the U.S., because they will increasingly combine routine tasks related to "technical expertise" with non-routine tasks that involve human skills related to "interpersonal interaction, flexibility, adaptability and problem-solving". As a result, employment polarisation "will not continue indefinitely". Even with a rapid increase in the capacities of IT technologies, digital capital and middle-skilled labour with a non-routine component (related to "human flexibility") should remain complementary inputs. Only middle-skilled labour that involves mainly routine technical task are facing displacement by digital capital.

AUTOR (2014) considers that the strong complementarity between technologies and labour that increases productivity and the demand for skilled labour is not likely to decline, as digital capital is a poor substitute for human abilities such as "flexibility, judgement, and common sense". Moreover, digital capital is complementary to high-skilled individuals who perform "abstract task-intensive jobs". Neither does it reduce employment in low-skilled "manual task-intensive" occupations, which do not offer opportunities for digital capital substitution. Their wages do not increase, however, because of low complementarity with digital capital and an abundance of labour supply. AUTOR (2014) concludes that the sharp declines in U.S. employment creation during the downturns after 2000 and 2007 are not due to a net substitution of labour by digital capital but were the result respectively of the bursting of the internet bubble and the financial crisis combined with a general trend of increased international competition.

FREY & OSBORNE (2013) provide a prospective analysis of the impact of digitisation of production on employment in the U.S. Their model accounts for the possibility that new digital capital (Machine Learning, Artificial Intelligence and Mobile Robotics) can substitute for non-routine tasks as well as manual intensive tasks. They show that 47% of total U.S. employment is at risk of computerisation ("job automation by means of computer-controlled equipment") over the next two decades, and they provide evidence of a strong negative relationship between wage and educational attainment and the probability of computerisation. The preceding wave of digital adoption ("Computer Revolution of the twentieth century") in the U.S. led to substitution of non-manual routine occupations by digital capital and hollowed-out middle-skilled, middle-income labour. By contrast, the adoption of new digital capital is expected to displace essentially low-skilled, low-wage employment in manual task-intensive services. New digital capital is not expected to substitute for occupations intensive in "creative intelligence" and "social intelligence" skills. FREY & OSBORNE's (2013) results imply a decrease in job polarisation, as new digital capital substitutes essentially for low-skilled and low-wage occupations, mainly located in services sector, while high-skilled jobs are the "least susceptible to computer capital".

Moreover, the role of international trade on the relationship between digital technologies and middle-skilled employment should also be considered. In particular, with the development of a strong ICT manufacturing industry in Asia, many U.S. middle-skilled jobs might have been offshored. As a result, the combined effects of globalisation and digital penetration might partly explain the hollowing out of middle-skilled jobs in the U.S. and other Western countries.

The hollowing-out of middle-skilled jobs in the U.S. explains jobless recoveries of the last thirty years

JAIMOVICH & SIU (2012a) show that the employment polarisation (the decrease in middle-skilled employment and the increase in the highest and lowest skill and income occupations) and the jobless recoveries (simultaneous post-recessions increase in aggregate output and much slower increase in employment) that emerged in the U.S. in the past thirty years are related. Jobless recoveries are mainly due to the loss of routine occupations caused by job polarisation. They first show that the disappearance of routine, middle-skilled employment occurs essentially during macroeconomic downturns and is therefore a business cycle rather than a gradual phenomenon unrelated to macroeconomic cycles. They show that the significant loss of routine, middle-income employment that occurs in recessions, induces jobless recoveries. Given that these routine occupations account for 50% of aggregate employment, almost all the decrease in aggregate employment can be attributed to contraction of those routine jobs. As employment growth during recoveries is concentrated in high-skill and, even more particularly, in low-skill jobs, it appears that aggregate employment does not rebound after recessions because routine employment is disappearing.

JAIMOVICH & SIU (2012b) argue that recoveries from recession are likely to be jobless in the future as the extent of employment polarisation grows with the progress of technologies thus increasing the range of occupations likely to be replaced by technology capital. They argue that as the pace of technological progress in IT technologies and robotics is not slowing down, "we should expect future recessions to continue to spur job polarisation. Jobless recoveries may be the norm".

■ Conclusion

Digital innovations are a major driver of aggregate productivity and output growth. In the long run the productivity growth of advanced economies tends to be associated to a very large extent to employment growth. The adoption of digital technologies may however lead to increased concentration of wealth as the returns of capital accumulation relative to labour increase and as inequalities in job market opportunities and labour income grow. There is thus a risk that technology-induced productivity shocks in the next years will contribute to such growth in inequalities.

Nonetheless, inequalities might be offset by new market opportunities brought by the penetration of digital technologies in the production system. Economic changes induced by digital technologies relate to a process of Schumpeterian creative/destruction, whereby new occupations do replace obsolete activities. The effect of digital innovations on productivity, employment and income distribution might also differ across industries, and across the type of geographical area. To avoid a growth in inequalities and achieve inclusive digital growth, a redistributive policy could be adopted to promote the widespread diffusion of digital skills within society as a whole. AGHION (2012) argues that macroeconomic policy must sustain the growth of nations at the level of technological development where "frontier innovations" generate future growth. To do so, it should foster the accumulation of human capital through "research education" and investment in skills by firms which must be incentivised to invest in R&D. Moreover, as claimed by AUTOR (2015):

> "The issue is not that middle-class workers are doomed by automation and technology, but instead that human capital investment must be at the heart of any long-term strategy for producing skills that are complemented by rather than substituted for by technological change".

Further research is still needed, however, to assess the employment effects of new generations of digital technologies and services. In particular, the potential impact of digital platforms on traditional services markets is deemed so significant that further analysis will be needed.

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