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ICT-induced Technological Progress and Employment: a Happy Marriage or a Dangerous Liaison? A Literature Review

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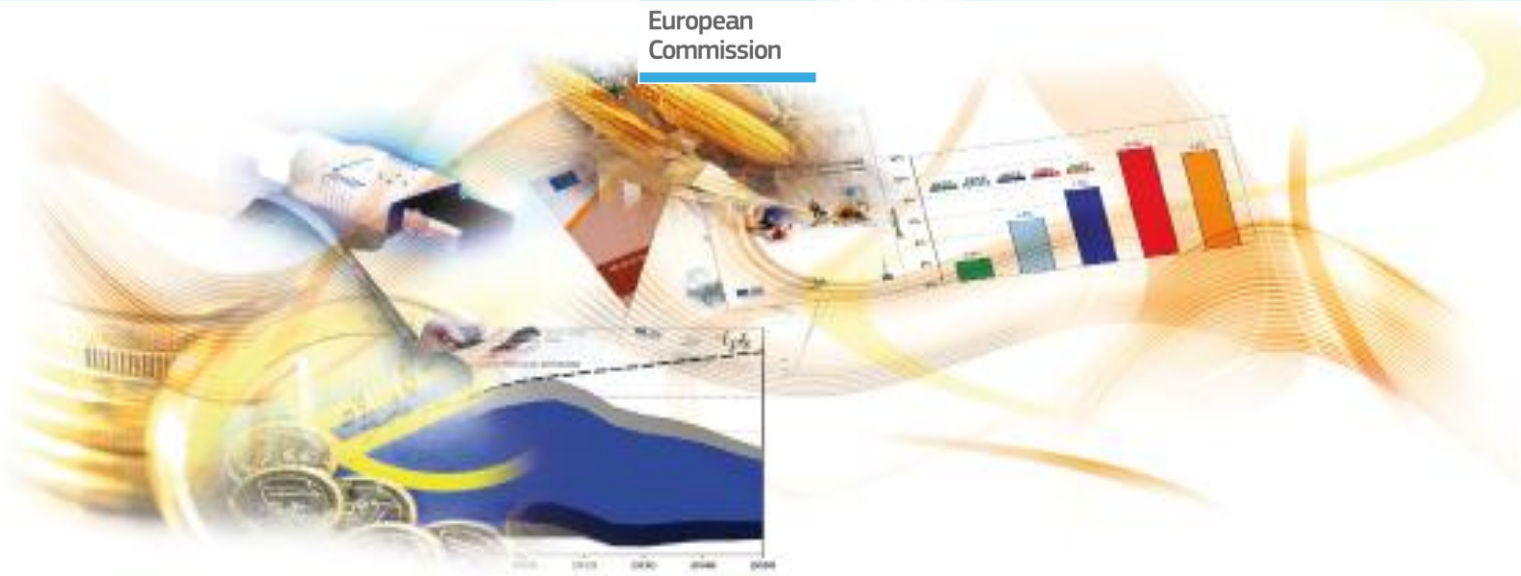
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ICT-induced Technological Progress and Employment: a Happy Marriage or a Dangerous Liaison? A Literature Review

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Abstract

This report surveys the literature on the employment impact of ICT. Two competing views - compensation and substitution theory - dominate the current economic debate. The first assumes that the labour-saving impact of technological progress is counterbalanced by various compensation mechanisms. The second asserts that technology cause job displacement, leading to polarization, de-skilling and possibly a jobless economy. Recent employment trends are often seen as indicative of mismatches between rapidly changing demand for skills and slow adjustment in the supply. Despite a wealth of theoretical models and empirical evidence, a consensus regarding the employment effect of ICT remains elusive. While there are many empirical studies on technological progress in general, few are based on specific ICT indicators. Our review devotes equal space to each mainstream economic theory on the complex connection between technology and employment, while giving greater emphasis to those studies which specifically look at ICT and that provide empirical support to sound theoretical grounds. This report recommends further empirical research on the specific employment impact of ICT.

Table of Contents

LIST OF TABLES AND FIGURES	5
SUMMARY	7
1 INTRODUCTION: ICT AND EMPLOYMENT IN THE POLICY AND RESEARCH DEBATES	14
2 COMPENSATION FRAMEWORK	19
COMPENSATION MECHANISMS.....	19
DISCUSSION OF COMPENSATION ARGUMENTS IN LITERATURE.....	20
3 SUBSTITUTION FRAMEWORK.....	25
END-OF-WORK LITERATURE	25
SKILL-BIASED TECHNOLOGICAL CHANGE	26
TASK-BASED FRAMEWORK AND POLARIZATION.....	29
GLOBALIZATION VS TECHNOLOGY DEBATE	31
TASK-BASED MODELS WITH ENDOGENOUS TECHNOLOGICAL CHANGE AND LABOUR SUPPLY, TRADE AND OFF-SHORING	33
4. FURTHER PERSPECTIVES OF EMPLOYMENT IMPACT OF ICT	35
MULTI-CHANNEL EFFECT OF ICT ON EMPLOYMENT	35
PRODUCT AND PROCESS INNOVATION	36
MEASUREMENT APPROACHES: LEVELS OF AGGREGATION	38
5 CONCLUSIONS AND SOME POLICY IMPLICATIONS	45
REFERENCES.....	50

List of Tables and Figures

Table 1: Labour market outlook - Euro area and the EU (2010-2013), annual percentage change 15

Table 2: Long-term employment and working time change, % 22

Table 3: Determinants of employment change in 21 manufacturing industries in Denmark, Germany, Italy, the Netherlands and Norway 37

Table 4: Decomposition of employment dynamics in composition and sector effects (%)..... 41

Figure 1: Unemployed persons, in millions, seasonally adjusted, EU-27 and EA-17, January 2000 - February 2013 (%) 15

For the time being, we may draw the important conclusion that the structural dynamics of the economic system inevitably tend to generate what has rightly been called technological unemployment. At the same time, the very same structural dynamics produce counterbalancing movements which are capable of bringing macroeconomic condition...towards fulfilment, but not automatically

Pasinetti, L. 1981, p.90

The naïve view of ICT as simply a process of automation and job destruction has its counterpart in the equally naïve view of ICT as a purely positive source of new employment. Any sophisticated attempt to assess the employment effect must take into account both job destruction and job creation.

ILO, 1995, p.57

The relationship between technology and employment turns out to be a very serious topic which cannot be dealt with through anecdotal generalization or mechanistic hypotheses.

Spiezia and Vivarelli, 2000, p. 21

Summary

Employment and ICT occupy an important place in the Europe 2020 strategy

Being one of the key EU economic policy domains, employment naturally occupies an important place in the *Europe 2020*, a EU strategy for the coming decade. As recognised by the EC President J. M. Barroso, high level of employment is the first among the five objectives to be reached by 2020.² In order to achieve the policy objective, which requires an increase in the employment rate for the working age population to at least 75%, it is crucial to arrive at a clear understanding of the forces that are driving labour dynamics in the EU.

The policy debate largely revolves around the role ICT play in changes to the work environment. The *Digital Agenda for Europe (2010)*³ seeks to take advantage of the potential offered by the rapid progress in ICT and addresses the issue of digital skills and inclusion. Another part of the *Europe 2020* overall strategy, the *Agenda for New Skills and Jobs (2010)*⁴ addresses structural change in the labour market and suggests concrete actions to adapt European workers' skills to the changing working environment. In April 2012 Commission presented new measures and identified key opportunities for EU job-rich recovery in its *Employment package*,⁵ aimed at generating synergies in the employment dimension of a number of EC flagship initiatives, such as *New Skills and Jobs*, *Digital Agenda for Europe*, *Resource-Efficient Europe*, and *Youth on the Move*.

A thorough understanding of the mechanisms underlying the relation between ICT and employment is crucial

ICT have dramatically shaped labour markets over the recent decades: employment dynamics have been marked by changes in both the nature of the tasks performed within jobs and the distribution of these tasks across sectors. The right model, assumptions, and data are essential for generating reliable evidence in support of policies aimed at promoting a sustainable societal impact. To this end, it is important to review and summarize extant theories and their empirical foundation.

Literature review on ICT and employment is complicated by a lack of consensus in both the theoretical and empirical studies

This report provides an overview of current perspectives on the employment impact of technological progress while paying a special attention to the effect of ICT. The task is complicated by a lack of consensus in both the theoretical and empirical literatures on the relation between ICT and employment. Depending on their starting assumptions and on the data to hand, researchers have drawn radically different conclusions ranging from the optimistic

² President Barroso on Europe 2020,

http://ec.europa.eu/europe2020/index_en.htm

³ EC (2010d), *Digital Agenda for Europe* is a part of the overall *Europe 2020* strategy for smart, sustainable and inclusive growth,

<http://ec.europa.eu/digital-agenda/en/our-goals>

⁴ EC (2010b), <http://ec.europa.eu/social/main.jsp?catId=958&langId=en>

⁵ EC COM(2012d) [http://eur-](http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=CELEX:52012DC0173:EN:NOT)

[lex.europa.eu/LexUriServ/LexUriServ.do?uri=CELEX:52012DC0173:EN:NOT](http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=CELEX:52012DC0173:EN:NOT)

suggestion that ICT is a major driver of employment creation, to the pessimistic view that ICT induces pervasive technological unemployment culminating in workless economies.

Our reading of economic literature on the employment impact of technological change suggests that state of the art in the current discussion can be characterised by

1) *a division of theoretical approaches adopted by empirical researchers into two competing camps, compensation and substitution frameworks, and*

2) *a convention between most researcher on several theoretical and empirical aspects of the employment impact of ICT.*

Most studies on employment effect of ICT support one of the two competing economic theories

The literature offers a wide range of theories and measurement techniques that can be applied for assessing the employment effect of ICT, most of which support one of the two *competing economic theories*, compensation and substitution frameworks. Traditionally, these two frameworks have influenced economic policies since the previous century.

Compensation framework suggests that the labour-saving effect of ICT is counterbalanced by market compensation mechanisms

The neo-classical **compensation framework** is based on the belief that the initial labour-saving impact of technological progress is counterbalanced in the long-run by market compensation mechanisms. Those mechanism that are most relevant to the employment impact of ICT and are most applicable to modern economic conditions, include: job creation through *commercialization of new products and demand for new equipment*; job creation through *lower unit costs of production*, which in competitive markets translates into decreased prices followed by an increase in demand and, finally, to additional production and employment in the longer term; job creation through the *higher income and consumption* derived from the cost savings due to the innovation, which increases demand and, consequently, production and employment. A number of empirical studies provide analyses of the employment effect of ICT-induced innovations taking into account the aforementioned compensation mechanisms jointly and separately.⁶

The substitution framework puts forward the view that the labour-saving effects of ICT cause employment displacement, leading to job polarization and/or de-skilling, and, in its extreme interpretation, to a jobless economy. In the mid-1990s, these extreme end-of-work theories attracted research and public attention to the polarization of the labour market and the disturbing hollowing out of routine tasks belonging to the medium-skilled medium-paid occupations, which can be more easily automated than high-skilled or low-skilled tasks. In the

⁶ Evangelists (2000), Simonetti et al (2000), Spiezia and Vivarelli (2000), Harrison et al (2005) and others

Substitution theories suggested that computers substitute workers, and attracted attention to the polarization and globalization of the labour market

view of skill-biased technological progress (SBTC) and a polarization hypothesis, the recent employment trends should be seen as indicative of pervasive mismatches between rapidly changing demand for labour and a trailing adjustment in the skill composition of the labour supply. A more nuanced approach, a task-based framework points to a more subtle impact of technology on labour demand for different jobs by analysing the skill content of jobs. Similarly, the globalization hypothesis points to factors that cause an upwards shift of labour demand towards skilled workers, which is not matched by an equally large increase in the supply of these workers, but derives from the international trade literature. A recent study suggests that employment polarization trend has been replaced by the de-skilling of labour in the US,⁷ however there is no evidence of this tendency for the European labour markets.

Conventions in literature on several aspects of employment effect of ICT can be summarised as follows.

Impact of ICT on employment is multi-channel and can be direct and indirect

Most researchers now agree that the impact of ICT on employment is **multi-channel**. From a macroeconomic perspective, the employment impact of ICT can be direct, through the growth of the ICT-producing sector, and indirect through multiplier effects and externalities taking place in the ICT-using sectors. Moreover, some authors point at a third type of the ICT effect on employment – effects on market structure of qualitative and quantitative nature, that influence the type of employment on demand, the skills required and even the labour market configuration. The multichannel character of the ICT-employment relation is associated with serious empirical challenges, mainly related to construction of a proper aggregate proxy of ICT-led innovation and to the existence of the whole range of determinants of changes in employment trends that are unrelated to technological progress (macroeconomic and cyclical conditions, the institutional settings, and others).

Product and process innovations result in distinct employment effects of ICT

A convention in the literature on the employment effect of ICT seems to have been established in which a distinction is drawn between **product and process innovations**. In practice, the distinction between the two types of innovation is not always clear, since process innovation often accompanies product innovation and vice versa. However, a number of papers⁸ using representative and internationally comparable data⁹ have collected evidence over two decades to show that European manufacturing employment has experienced periods of poor

⁷ Boeudry et al (2013)

⁸ Vivarelli et al (1996), Pianta (2000, 2001), Antonucci and Pianta (2002), Evangelista and Savona (2003), Mastrostefano and Pianta (2007)

⁹ Based on innovation surveys of firms

growth or job losses, and pointed to weak product innovation and the prevailing labour-saving process innovation as the main causes. This perspective allows us to identify more clearly the relative weakness of the European industry mainly represented by the non-ICT slow-growing sectors with reduced employment potential.¹⁰ Many studies¹¹ suggest that different employment outcomes result from the different orientation of national innovation and production systems: positive employment change has always been greater in product-oriented industries, while technological unemployment accompanies innovations in process-oriented sectors.

Relation between ICT and employment have been studied at different levels of aggregation – macro, sector, and firm levels

Studies of the relation between ICT and employment have been undertaken at different **levels of aggregation** – macro, sector, and firm levels – which allow different aspects of this relation to be unveiled. Each of the three levels of aggregation has its merits and drawbacks, and an important concern for policy is that the final employment impact of ICT depends to a large extent on institutional mechanisms which can be very different at the micro, sectoral and macro levels, and can vary in different contexts (i.e. in different countries or sectors).

Relation between ICT and employment is a fast evolving field

Stemming from the constant improvement of conceptual economics and statistical data, the **main conclusions** of this literature review can be summarized as follows. Economic theory supported by empirical studies suggests a rich variety of changes in different aspects of employment in response to technological advances in modern economies. However, a comprehensive overall picture remains elusive. The relation between ICT and employment is a fast evolving field that includes several leading theories. Being a highly dynamic technology, ICT influences labour markets and human capital through many transmission channels, which are often difficult to capture both conceptually and empirically. Depending on the particular aspect of ICT impact on the labour market and on the choice of proxies for ICT and for employment, a researcher may draw different conclusions.

Based on the review of economic literature on ICT and employment, we suggest several **policy-relevant insights** into the employment effect of ICT-induced technological development.

(1) *Polarisation of employment* into high and low paid jobs at the expense of medium-paid jobs, has firmly entered the policy

¹⁰ Piacentini and Pini (2000), Pianta (2000), Pianta and Vaona (2007), Mastrostefano and Pianta (2007), Malerba (2002), Antonucci (2003), Grajek, M. (2012), Veugelers (2012) and others

¹¹ Harrison et al (2005), Pianta (2000), Antonucci and Pinata (2002), Antonucci, Meliciani and Pinata, (2003), Pianta (2007), Van Reenen (1997), Garcia et al (2002) and others.

In view of the polarization of jobs it is crucial to improve labour market matching and adaptability of workers to change

debate¹² and has been extensively documented in the economic literature. The polarisation dynamics coincide with increased demand for high educational and skills profiles, thus compromising the chances of re-employment and access to well-paid jobs for lower-skilled people who became unemployed during the recession. This points to one of the issues that polarization theory raises – skills mismatches and adapting the supply of labour to skills demanded in the labour market, which holds back the post-crisis recovery (2012 DG ECFIN’s economic forecast¹³). It is thus crucial to improve labour market matching and adaptability of workers to change, and points to issues of more adaptable wage-setting mechanisms, income security implications of low-skilled workers and the need for up- and re-skilling of the workforce at all levels.¹⁴ However, it is important to bear in mind that the increase in the rate of change in skills demand also lowers the rate of return to educational investments. Moreover, SBTC theory does not guarantee that even a fully matching supply and demand for skills brings us back to full employment.

Polarization, combined with the diverging trends between productivity and real wages growth adversely impacts employment through depressing final demand

(2) Another issue, closely related to the polarization trends in the European labour markets, is rising income inequality through depressed earnings of the low and middle income groups.¹⁵ At the same time, the very favourable dynamics of labour productivity in recent years, largely boosted by the ICT innovations, has not been associated with similar adjustments in real wages.¹⁶ Several authors¹⁷ point out that employment dynamics related to ICT innovation need to be linked to the dynamics of (different components of) *final demand and income distribution*. Income redistribution through the tax system could be considered with a view to addressing labour market inequalities by improving employment participation, raising low wages (especially where they lag significantly behind productivity developments). However, while there is room to increase the quality and efficiency of public spending to mitigate inequalities (as emphasized by EC, 2012a), income redistribution policies have their limits, especially within the current fiscal environment in most EU countries.

¹² EC (2012a and 2012c), OECD (2011), and UNESCO (2012) to cite the most recent policy documents

¹³ EC (2012c)

¹⁴ In line with the recommendations of the recent EC, OECD and UNESCO publications: EC (2012a), OECD (2011), UNESCO (2012)

¹⁵ While the income effect of ICT is beyond the scope of this paper, mentioning wages is unavoidable in explaining certain employment effects.

¹⁶ Fisher and Hostland (2002), Russell and Dufour (2007), Sharpe et al (2008), EC (2012a)

¹⁷ Díaz-Chao, Ángel (2009), Piacentini and Pini (2000), Vivarelli (1995), Vivarelli and Gatti (1995)

Employment growth through stimulated demand can be achieved by empowering ICT users

(3) Another way to link supply and demand factors is to stimulate the creation and organization of the markets for ICT and ICT-enabled new products, for example by empowering ICT public and private users. For societies to obtain the advantages of the ICT it is required that the great majority of the citizens have the necessary knowledge to participate in the digital economy. This emphasizes that education policy should be directed toward the use of digital technologies. The institutional context, as shown in the compensation theory literature, appears to be a very important factor in the analysis of the employment effects of ICT as it allows economic policies to encourage demand from public and private final consumers for ICT products and services, both at home and abroad.

Reduction of working time does not necessarily have a negative impact on the jobs quantity and quality

(4) Several papers address the structural issue of *destruction of working time and redistribution of available employment* through lowering working time per employee. Spiezia and Vivarelli (2000) present evidence suggesting a pattern of labour destruction that has not turned into job destruction only because of a progressive reduction in per capita annual working hours. The findings of another study, by Macias et al (2009), show that there has been an increase in the proportion of jobs with long hours of work towards the top of the wage distribution in most of the EU Member States over the period 2000-2005. Additionally, the authors claim there has been an increase in job quality in most European countries over the period of 1995-2005. While labour destruction, even when not translated into jobs destruction, may be considered counter-productive, the decrease in the total number of hours worked combined with increasing quantity and quality of employment and welfare is not necessarily a negative socio-economic outcome. Moreover, it suggests policy interventions through institutional adjustments in the form of a progressive reduction in per capita annual working time, as has happened in several European countries.

Product-innovation oriented industries that generate and apply ICT-enabled innovations are the main engine of job creation in the medium and long term

(5) Despite the growing number of ICT job vacancies, the non-ICT slower-growing sectors with reduced employment potential are still heavily represented in *the sector composition of European industries*.¹⁸ A number of papers have collected evidence over the last three decades to show that European manufacturing employment has experienced periods of poor growth or job losses, and pointed to weak product innovation and prevailing labour-saving process innovation as the main causes.¹⁹ As empirical findings suggest, most of the actual employment gains in Europe are due to the increase of the relative share of the service sector with respect to the industrial sector. This job-

¹⁸ Pianta, 2000, Pianta and Vaona (2007), Mastrostefano and Pianta (2007), Malerba (2002), Antonucci and Pianta (2002), Antonucci (2003) and others

¹⁹ Vivarelli et al (1996), Pianta (2000, 2001), Antonucci and Pianta (2002), Evangelista and Savona (2003), Mastrostefano and Pianta (2007)

creating resource could be further exploited together with the job-creating potential of product-innovations led by ICT in the traditional fashion of the industrial policy tools, like taxes and subsidies, to favour one sector over another. It is important though to bear in mind the actual policy objective of employment creation and not to slip into an industrial policy of “picking winners” or selecting “national champions” which have been shown to be inefficient by empirical studies.

1 Introduction: ICT and employment in the policy and research debates

Full employment has always been one of the EU policy objectives. While the official birth of *the European Employment Strategy* dates back to *the Luxembourg Employment Summit* of 1997,²⁰ it is only in the 2000s with the adoption of *the Lisbon Strategy for Growth and Jobs*²¹ when employment targets were officially allied to the technological developments. While the EU economy is struggling with the joint consequences of the 2008 economic recession and the sovereign-debt crisis, and steadily growing unemployment has become a major economic policy concern, discussions on the structural dynamics of the labour markets are gaining in importance.

The European Commission's overall policy strategy – crystalized in the *Europe 2020 (2010)* – reiterated the strong emphasis on technology-induced changes in dynamics and structure of employment. As recognised by the EC President J. M. Barroso, high level of employment is the first among the five objectives to be reached by 2020.²² In order to achieve the policy objective, which requires an increase in the employment rate for the working age population to at least 75%, it is crucial to arrive at a clear understanding of the forces that are driving labour dynamics in the EU.

A series of policy measures have been announced that revolve around the changes that ICT technology induces in the work environment. The *Digital Agenda for Europe (2010)*²³ seeks to take advantage of the potential offered by the rapid progress in ICT and addresses the issue of digital skills and inclusion. Another part of the *Europe 2020* overall strategy, the *Agenda for New Skills and Jobs (2010)*²⁴ addresses structural change in the labour market and suggests concrete actions to adapt European workers' skills to the changing working environment by development of right skills, creating new jobs and improving the quality of existing ones. In April 2012 Commission presented new measures and identified key opportunities for EU job-rich recovery in its *Employment package*,²⁵ aimed at generating synergies in the employment dimension of a number of EC flagship initiatives, such as *New Skills and Jobs*, *Digital Agenda for Europe*, *Resource-Efficient Europe*, and *Youth on the Move*. However, these policy initiatives do not always follow a comprehensive approach that encompasses the complexity of the ICT-employment nexus. For example, the main focus of the *Employment Package* seems to be on the job-creating potential in ICT-producing sectors and ICT skills²⁶ while the job displacement effect of ICT remains under-emphasised.

²⁰ See:

http://europa.eu/legislation_summaries/employment_and_social_policy/community_employment_policies/c_11318_en.htm

²¹ http://ec.europa.eu/archives/growthandjobs_2009/

²² President Barroso on Europe 2020, http://ec.europa.eu/europe2020/index_en.htm

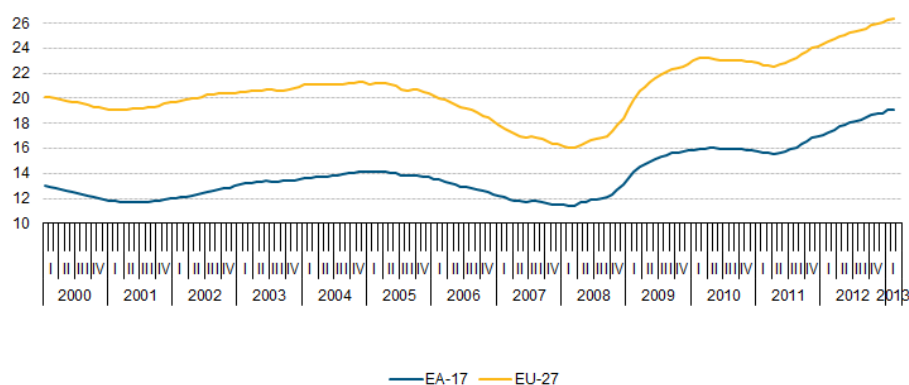
²³ EC (2010d), *Digital Agenda for Europe* is a part of the overall *Europe 2020* strategy for smart, sustainable and inclusive growth, <http://ec.europa.eu/digital-agenda/en/our-goals>

²⁴ EC (2010b), <http://ec.europa.eu/social/main.jsp?catId=958&langId=en>

²⁵ EC COM(2012d) <http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=CELEX:52012DC0173:EN:NOT>

²⁶ See, for example, the EC (2012e), "Exploiting the employment potential of ICT"

Figure 1: Unemployed persons, in millions, seasonally adjusted, EU-27 and EA-17, January 2000 - February 2013 (%)



Source: Eurostat (2013).

Very weak economic growth in the post-crisis years in most Member States – and negative growth in some of the worst affected States – was accompanied by a strong increase in unemployment in the EU27, from around 16 million in early 2008 to over 26 million in 2013 (Eurostat, 2013). Moreover, leading indicators suggest a weak outlook for the EU labour markets in the coming years, aggravated by strained public budgets and reductions in public sector employment. Up-to-date data on employment and unemployment dynamics in Europe can be consulted in Figure 1, and Tables 1.

Table 1: Labour market outlook - Euro area and the EU (2010-2013), annual percentage change

	2008	2009	2010	2011	2012*	2013*
<i>Employment level (ml)</i>	1.0	-1.8	-0.5	0.2	-0.2	0.2
<i>Employment rate (%)</i>	65.8	64.5	64.1	64.3	64.2	64.3
<i>Unemployment level (million)</i>	16.8	21.5	23.1	23.2	24.7	24.7
<i>Unemployment rate (%)</i>	7.1	9.0	9.7	9.7	10.3	10.3
<i>Labour productivity, whole economy</i>	-0.6	-2.6	2.5	1.4	0.4	1.2
<i>Real GDP (%)</i>	0.3	-4.3	2.0	1.6		

Note: (*) refers to Spring 2012 forecast. Unemployment and employment rates are calculated as a percentage change in the labour force

Source: EC (2012), Eurostat (2013)

A variety of interrelated and mutually-enhancing factors are determining the employment dynamics in the EU. Depressed domestic and foreign demand in the economic recession is, probably, among the most cited causes of the currently raising unemployment. While economic stagnation can be made responsible for the decline in total demand for labour, major changes in the *structure* of employment, such as the shift from agriculture and manufacturing to services, and the shift from manual to non-manual jobs are usually linked to other causes. One of the factors that may contribute to destroying European jobs and shifting them abroad is globalization of production and consumption, which induces

international competitiveness pressure. Another important factor that changes the structure and determines the dynamics of employment in the recent decades is technological advances spurred on by information and communication technologies (ICT). This latter factor of employment dynamics is one of the major topics discussed in the context of the EU employment policy.

There are several theoretical explanations for the effect of technology on employment that have already influenced economic policy at different points in time. The dominant economic argument, put forward in the early 1980s, emphasized that the labour saving effects of technological change would be offset by market mechanisms. A logical consequence of the compensation theory framework is that persistent unemployment must be due to market imperfections that prevent a proper functioning of the compensation mechanisms. This view was reflected in many official European and OECD studies in the 1980s and 1990s, and coincided with a conceptual translation of structural unemployment into market frictions. High unemployment in Europe was blamed on the over-regulation of the labour markets. This culminated in the *OECD Job Study* (1994), and had largely influenced the spirit of the 1997 *Luxembourg Summit* where monitoring of the Member States employment policies was proposed. As a result, new labour market regulations were introduced throughout the EU, which, in several cases, resulted in significant reduction of unemployment (Denmark and the Netherlands are the most cited examples in this regard). Yet, the partial success of these measures made many researchers and policy-makers reflect on an alternative explanation for the sources of long-lasting unemployment.

By the turn of the millennium, public attention was again drawn to the labour-saving effects of technology, and ICT-induced technological progress was perceived to cause not only displacement of workers but also changes in both the nature of the tasks performed within jobs and the distribution of these tasks across sectors. Skill-biased technological change became a major issue and the substitution theory gained in popularity: technology can not only substitute human labour but can also affect different tasks and skills in different ways. The spectacular technological advances in ICT have given the old debate on the relation between technical change and the structure of the labour market fresh momentum: in 2000 a *Lisbon Strategy* officially linked employment dynamics to the technological development by looking at jobs in the context of the knowledge-based society. Since then, policy debate has largely revolved around the ICT and the changes to the work environment, and the recent EU policy initiatives largely focus on skills matching and retraining, and on ICT skills in particular.

However, the role of ICT in employment dynamics remains ambiguous.

Being a highly dynamic technology, ICT influences labour markets through many transmission channels, which are often difficult to capture both conceptually and empirically. Depending on the particular aspect of ICT impact on the labour market and on the choice of proxies for ICT and for employment, a researcher may draw different conclusions. Thus, on the one hand, in economies increasingly dependent on ICT, innovation is often seen as a major driving force behind jobs creation, and individuals with the requisite ICT skills are expected to have better opportunities for employment. On the other hand, ICT can also lead to loss of employment as tasks are automated. Moreover, the above two effects can coexist and be mixed differently in different institutional and industrial settings. They can also show up differently in data depending on the assumptions and techniques employed by an empirical investigator. As a result, the empirical analysis in

this area is complex and requires very clear assumptions about the relationship between variables, the proxies used and the underlying theoretical model.

The alternative interpretations of the relation between ICT and employment caused the division of theoretical economists into two competing camps. The conventional neo-classical school supports the *compensation theory*, according to which the labour-saving effects of all technological revolutions and of ICT in particular are undone in the long-run by means of market compensation mechanisms. The proponents of these views predominantly come from Europe. In contrast, the *substitution* or the *end of work* literature, originated by US authors, suggests that the labour-saving effect of new technologies leads to a jobless society. The micro-economic foundations for these two approaches depart from two opposite assumptions. The optimistic compensation approach assumes that labour markets clear under all conditions: perfectly flexible wages, prices and quantities respond to technological changes by preserving full employment. The pessimistic end-of-work approach builds on the opposite assumption, that wages or prices are locked in disequilibrium. These two schools have nurtured theoretical and empirical discussion and have influenced the policy debates for decades.

Though the origin of the two competing theories, compensation and substitution frameworks, described in this paper predate the ICT breakthrough, they became increasingly popular in the recent technological context as they offer tractable theoretical frameworks that can be fit to data and provide policy conclusions. Having departed from different (if not opposed) assumptions, they suggest alternative explanations to the relation between ICT and employment, and consequently point to contrasting measures to deal with technological unemployment. Interestingly enough, Vivarelli's (1996) empirical study indicates that the two theories each fail to account for the impact of technology on employment in the proponents' own geographical regions, though each fits the data relatively well in their intellectual opponent's region. Though the US has demonstrated a capacity for creating new jobs, the total amount of work has shrunk in European countries.

In this paper, we will give a detailed account of the theoretical grounds for these two alternative interpretations of the economic impact of technology, focussing specifically on the relation between ICT and employment. We will pursue the objective of bringing more clarity into this issue by examining the available empirical evidence regarding the relationship between technology (in general, and ICT technology in particular) and employment.

We find that there is a large volume of empirical research on the relationship between technology and employment. However, our reading suggests that, despite a wealth of theoretical speculation and empirical evidence, a consensus regarding the employment effect of ICT remains elusive. Before drawing conclusions about the employment impact of ICT, it is important to carry out a careful check of the ICT indicators that are used to fit empirical results to a theoretical framework. There is no consensus on possible or negative overall impact, not between the two major theoretical schools and not even within each school. One major difficulty here is to separate the impact of technology from other factors: business cycles and globalization mainly. Over the last decade economic research has shifted attention from the overall employment impact to the impact on specific skill levels. While there are noticeable shifts in the skill composition of employment, there is again no consensus on the direction and magnitude of these shifts.

We also find that there is little empirical research that focuses specifically on the impact of ICT on employment and thus very little to say on the net impact of ICT on employment. Despite claims by some more popular consultancy-type reports (2011 McKinsey Report states that 2.6 jobs were created for every one destroyed by ICT²⁷) there is no convincing evidence to show the positive or negative impact of ICT on employment. A major obstacle here is to find credible indicators of ICT use at macro, sector or firm level. The lack of research has left the door wide open to a more speculative “end of work” school of thought that claims that past data are a poor guide for the extent to which ICT could replace human labour in future. This paper only summarizes the available empirical literature; it does not look into more speculative theoretical debates about the future potential for substitution.

We conclude that the compensation and substitution framework, the two dominant theories in economics to explain the link between technological innovation and employment, offer a rich diversity of theoretical perspectives and evidence-based insights. At the same time they leave the door open for a wide diversity of policy conclusions that do not facilitate the task of EU policy makers to promote policies that stimulate growth and job creation. The compensation framework suggests that negative effects of technological change on employment can be reversed provided the market-based compensation channels are kept open, and are carefully taken into account, together with specific institutional settings in which they operate. There may be some role here for labour market institutions and wage bargaining. However, for some European countries there is evidence that this did not prevent jobless growth. The substitution framework has analyzed a variety of shifts the skills composition of demand for labour and reduces the policy toolkit to educational and supply side policies, possibly complemented with income redistribution policies. Moreover, there is comparatively little empirical research on the specific impact of ICT technology on employment. While some sectoral and firm-economic research points to positive employment effects, there is no evidence yet that this translates into an overall positive effect. We end the paper in traditional fashion with some suggestions for further research to fill the research gap on the relationship between ICT and employment.

The remainder of this literature review is structured as follows. Chapters 2 and 3 provide a broader outlook on the two alternative interpretations of the relationship between technological progress (including ICT) and employment, with a discussion of the theoretical basis and supporting empirical arguments. Chapter 2 outlines the compensation theory which is supported by the neo-classical economic school, and Chapter 3 deals with the substitution framework that ranges from the radical end-of-work hypothesis to the more academically cautious theories of skill- and task-biased technological progress. In Chapter 4, we describe the main consensuses reached in economic studies on the relation between ICT and employment, and on the levels of empirical analysis used to capture the employment effect of ICT. Chapter 5 summarizes the main findings of this literature review and suggests some policy conclusions. Chapter 6 suggests some directions for further research.

²⁷ Pélissié du Rausas et al (2011)

2 Compensation framework

Traditionally, economics as a discipline has tended to dismiss major concerns about the possible harmful effects of technological progress on employment. *Compensation theory* has been particularly successful in this respect. This framework, which remains popular among contemporary economists, is based on the belief that technological change has a positive impact on employment in the long term. While the direct effect of technological progress is labour-saving, compensation theory argues that there are indirect market-based compensation mechanisms that can counterbalance this initial labour-saving impact, or even reverse it.

In this section we examine the theoretical framework and the available empirical evidence in support of this view. Most of this research revolves around general technological innovation and was not designed with ICT in mind. However, we address the compensation argumentation from the ICT angle and, where available, review relevant empirical studies.

Compensation mechanisms

Several authors provide a comprehensive review of these compensation mechanisms (Vivarelli, 1995; Pianta, 2004); Vivarelli and Pianta, 2000; Petit, 1995). Below we summarize those channels that are most relevant for the employment impact of ICT and most applicable to modern economic conditions.

1. Job creation through new products.

Commercialization of new products and demand for new equipment due to technology and innovation create new jobs. This mechanism is believed to be the most powerful means of counterbalancing technological unemployment. It has been extensively studied in the economic literature and empirical evidence has been put forward to support the idea that the most important employment effects of product innovations are likely to be positive compensation resulting from increases in demand for a firm's products. Katsoulacos (2003) suggests that product innovation generates two types of effect, a welfare effect (development of either entirely new goods or differentiation of mature goods) and a displacement effect (substitution of established by new products), with the former being the primary determinant of the overall impact of product innovation on employment. The magnitude of the welfare effect depends on the nature of competition and the delay with which rivals react to the introduction of new products. In practice, however, the distinction between product and process innovation is not always straightforward, and one often accompanies the other, especially in services (see, for example, Harrison et al, 2008).

2. Job creation through lower unit costs of production.

While leading to the displacement of workers, process innovation decreases the unit cost of production, which in competitive markets translates into reduced prices followed by an increase in demand (through income and substitution effects) and, finally, to additional production and employment in the longer term. This line of reasoning stems from two basic assumptions: first, that in a competitive economy supply generates its own demand; and second, that innovation plays a core role in competition in national and international markets.

This argument has generated two main criticisms. The first attacks the assumption of perfect competition by suggesting that in oligopolistic markets cost savings are not necessarily translated into decreasing prices. The second critique is based on the existence of demand constraints that lower demand elasticity through delays in expenditure

decisions. These delays may occur due to the complexity of consumer decision-making resulting from imperfect information, costly search, brand loyalty, pessimistic expectations and other factors.

Another mechanism related to decreased production costs works through the time lags between the actual decrease in costs and the decrease in prices. This allows innovative firms to accumulate extra profits and translate them into new investments, higher production and, hence, new jobs. The assumption behind this mechanism is that accumulated profits are entirely and immediately translated into additional investments, and that investments are labour-augmenting.

3. Job creation through higher consumption

A similar reasoning refers to the higher income and consumption derived from the cost savings due to the innovation. This leads to increased demand and, consequently, to increased production and employment, which may compensate for the technological unemployment.

This mechanism putatively works if workers share the productivity gains due to technological progress. It proved to be rather powerful throughout the 1950s and 1960s, when wages were to a large extent regulated in consultation with trade-unions and productivity gains resulted in increased real incomes. However, it tends to be weaker in a modern institutional setting where labour markets tend to be more competitive and union powers have decreased.

The magnitude of compensation effects 2 and 3 above are likely to depend on the behaviour of agents inside the firm and the nature of market competition. Thus, unions may attempt to transform any gains from innovation into higher wages, while managers may seek to use market power to increase profits²⁸ (and eventually, to translate them into investment). Both behaviours can dampen or even override the compensation effect.²⁹

Discussion of compensation arguments in literature

The theoretical battle has moved into the empirical arena as proponents of each theory search for more support. Compensation theorists' main empirical arguments in favour of a positive long-term employment effect of technology in general and ICT in particular, and their corresponding critiques, can be summarized as follows:

(1) *Historical evidence.* Previous technological revolutions invariably fuelled economic development without negative consequences for employment.³⁰ There is no reason to suppose that the ICT revolution will be an exception. This argument rests on the empirical evidence of cross-country employment trends (see, for example, Grey, 1950, OECD, 1996, Spiezia and Vivarelli, 2000, CEDEFOP, 2010). The most popular counter-argument is that this historical view ignores the secular decrease in per capita working time. When the average working time wedge is driven between total employment and total demand for labour, technological change has a net labour saving effect. In an empirical study of four European countries, Spiezia and Vivarelli (2000) present evidence suggesting a pattern of labour destruction which has not turned into job destruction only because of a progressive reduction in per capita hours of work. However, the decrease in the total amount of hours worked combined with increasing employment and welfare is not necessarily a negative

²⁸ Nickell (1999)

²⁹ Harrison et al (2008)

³⁰ See more on different waves of technological innovation in Smihula (2010)

socio-economic outcome. Workers may benefit from more leisure time and society benefits from a more equal distribution of the available work. Moreover, this example suggests policy interventions through institutional adjustments in the form of progressive reduction of the per capita annual working time may be effective in maintaining employment, as has happened in Europe.

(2) *The Solow Paradox in ICT.* This rather rhetorical argument states that technological progress could not be responsible for the acceleration in unemployment in the second half of the 20th century because growing unemployment was not accompanied by a productivity increase, or at least not by a productivity changes caused by ICT. As Robert Solow famously quipped "computers can be seen everywhere but in the productivity statistics".³¹ However, this apparent paradox was soon overcome in a number of economic studies. First, the economy as a whole and employment in particular may need additional time and effort to adjust to new technologies. If time lags are taken into account, the productivity increase did in fact take place. Second, technological change was not apparent to researchers several decades ago, when Solow made his widely-cited remark, because it was not properly documented in official statistical data. Today, this situation has changed.

(3) *Firm-level evidence.* The final argument is based on microdata that show that ICT deployment is associated with higher employment growth at the firm level, and with the size of the employment outcome, depending on whether product versus process innovation are implemented and on whether firms belong to the service or manufacturing sectors (Van Reenen, 1997, Chennels and Van Reenen, 2002, Garcia et al, 2002, Peters, 2004, Harrison et al, 2005). However, aggregation problems undermine this argument. A positive correlation between ICT and employment at the micro level can go hand in hand with the labour-saving dynamics at the macro-level, and says little about the overall long-term effect of ICT on employment (see more on the different levels of analysis in Chapter 4).

Spiezia and Vivarelli (2000) disentangle the trends in total working time and total employment. They look at historical trends in aggregate demand for work time in the US, Japan, Canada and four European countries (Germany, Italy, France and the UK) since the 1970s. Their descriptive analysis shows that the capacity to create jobs is stronger in the US, Canada and Japan, while the European countries perform more modestly on this score. Their findings also suggest a clear distinction between *job* and *work* creation / destruction: if one accounts for the changes in working time per employee, all four European countries show a pattern of labour destruction which has however not turned into job destruction because of a progressive decline in working time per employee. Additionally, this analysis shows an obviously lower GDP elasticity of working time in Europe compared to North America (see Table 2).

These figures point to the difficulties that European countries seem to have in translating technology-driven productivity growth and overall economic growth into employment growth. Clearly, the transmission mechanisms of the compensation framework do not work as well in Europe as in other countries. If one chooses total working time as a measure of the employment impact of technological innovation, these results point towards a pattern of long-term jobless growth in the EU. However, another study, by Macias et al (2009), is more optimistic. Their findings suggest that there has been an increase in the proportion of jobs with long hours of work towards the top of the wage distribution in most of the EU

³¹ Solow (1987).

Member States over the period 2000-2005. Additionally, the authors claim there has been an increase in the job quality in most European countries over the period of 1995-2005.

Table 2: Long-term employment and working time change, %

	<i>US</i>	<i>Canada</i>	<i>Japan</i>	<i>W. Germany</i>	<i>Italy</i>	<i>France</i>	<i>UK</i>
<i>Employment</i>	42.77	39.90	22.43	4.88	7.24	3.60	5.53
<i>Working time</i>	47.70	32.64	9.2	-9.27	-5.44	-8.63	-2.20
<i>Working time per employee</i>	3.46	-5.18	-10.8	-13.49	-11.82	-11.80	-7.32
<i>Real GDP</i>	69.97	66.00	69.92	45.1	53.34	47.49	51.78
<i>Working time elasticity w.r.t. GDP</i>	68.47	49.45	13.16	-20.55	-10.2	-18.18	-4.24
<i>Time interval</i>	1976-96	1976-96	1976-94	1973-90	1970-96	1976-96	1976-96

Source: adopted from Spiezia and Vivarelli (2000).

In the case of ICT, the impact on employment involves not one but a mixture of different compensation mechanisms. Moreover, some of them undergo considerable changes and take on new forms in specific production contexts: thus, for example, compensation "via new products" often takes the form of compensation "via new services"; and it is through the provision of a whole range of new services in virtually all economic sectors that ICT influences employment in the most radical way.

The OECD (2001, 2010) has documented a strong growth in service sector employment both in the US and in Europe, particularly in relatively highly-paid occupations and industries. Historically, the US and the UK are often used as examples of employment growth that is due essentially to the services sector (Piketty, 1998, Gadrey and Jany-Catrice, 1998, Evangelista, 2000, Licht et al, 1999, OECD, 2000 and others). At the same time, some doubts have been expressed in the literature as to whether the expansion of services can continue to function as the engine of job growth. This question cannot be answered unambiguously, mainly because the service sector's increased use of ICT is changing its skill structure in the same way as it did in manufacturing. Research shows that in every sector of services the share of highly qualified workers in innovative firms is larger than in non-innovative companies, and is largest in those sectors that rely more heavily on ICT for innovation.³² Thus, employment expectations in services can generally be rated as positive for employees with higher education, shifting the staff qualification structure towards more highly qualified workers.

However, as shown in Evangelista (2000), the aggregate figures may hide the differentiated employment impact of ICT with regard to firm size and sector affiliation. While larger firms' innovative activities show a strong labour-saving effect, innovative activities in small-size service firms have a job-creation outcome. In both groups of firms, workers with lower qualifications are affected most by the labour-displacing effect of ICT. The latter effect is confirmed by sectoral analysis: ICT's strongest labour-saving effect is observed among less qualified members of the labour force and is mainly concentrated in

³² Licht et al (1999).

the financial sector, in advertising and among science and technology-based service sectors such as R&D, engineering and technical consultancy.

These tendencies hint at changes in the employment structure that require a more nuanced explanatory framework combining compensation and substitution effects.

Harrison et al (2005) provide one of the most complete analyses of the employment effect of ICT-induced innovations, taking into account the aforementioned compensation mechanisms. They apply a sound theoretical model to the Community Innovation Survey data for four major European countries (France, Germany, Spain and the UK) in both service and manufacturing sectors. Overall, their results accord well with existing evidence at firm level, and provide explanations for both the strong positive effect of product innovation on employment and the typically ambiguous effects of process innovation. They find that compensation mechanisms offset the negative effect of ICT on employment with the outcome differing according to the specific production process. Thus, their results reveal that in manufacturing, although process innovation tends to displace employment, compensation effects are prevalent, and product innovation is associated with greater employment growth. The destruction of jobs through process innovation appears to be partly counteracted by compensation mechanisms that increase demand through lower prices. At the same time, consistent with the literature, they find no evidence of displacement effects associated with product innovation. Compensation effects resulting from the introduction of new products are significant even when the discarding of old products is taken into account. In the service sector they find less evidence of displacement effects from process innovation, and though less important than in manufacturing, growth in sales of new products accounts for a non-negligible proportion of employment growth.

Another comprehensive analysis of different compensation mechanisms that work to counterbalance technological unemployment through the process of creative destruction was proposed by Simonetti et al (2000). They tested a set of simultaneous equations in a macroeconomic model that jointly takes into account the direct labour-saving effect of process innovation, the different compensation mechanisms (and respective hindrances) and the job-creating impact of product innovation. They ran the three stages least squares regression equations on the US, Italian, French and Japanese data over the period 1965-1993 and showed that the most effective compensation mechanisms acted through a decrease in prices and an increase in incomes (especially marked in Europe). While the authors do not specifically measure the ICT variables in the study, this generalised framework provide useful insights into the nature of the employment-creation effect of different compensation mechanisms. The compensation mechanism through a decrease in wages was particularly pronounced in the US's flexible labour market. Their results confirm that both the history and the institutional structure of a country are important determinants of the strength of each compensation mechanism, and therefore policy interventions aimed at the creation of new jobs must take into account the specific institutional settings in which they operate.

3 Substitution framework

In this Chapter, we summarise the views and theories that suggest that in the era of ICT-induced technological change computers substitute labour. The array of these approaches range from the end-of-work literature that draws a gloomy picture of the decline of the global labour force, to the skill and task biased technological change approaches that suggest that computers substitute certain types of jobs and tasks leading to polarization of labour markets.

End-of-work literature

Rifkin (1995) laid out a bold and disturbing hypothesis that computer-driven unemployment was already upon us as we are entering a new phase in world history – one in which fewer and fewer workers will be needed to produce the goods and services for the global population. Since then, several, mostly North American, economists, businessmen and politicians have expressed their concerns about jobless economic growth due to ICT-based technological progress.

This hypothesis can be summarized as follows. All traditional sectors of the economy are experiencing technological displacement, forcing millions into unemployment. The only new sector emerging is the knowledge sector, made up of elite entrepreneurs, scientists, technicians, computer programmers, top professionals, educators and consultants. However, the increasing demand for these occupations is not expected to absorb more than a fraction of the workers displaced in the wake of the revolutionary advances in ICT.³³ Other analysts have suggested that employment will be substituted by ICT not only in traditional economic sectors but also in services: Hammer (1990) argued that computers would make management jobs redundant, while Rackhman (1999) predicted that e-commerce would lead to a radical shrinkage of sales jobs. Ford (2009) generalizes these predictions by suggesting that, at some point in future, ICT will be able to do the jobs of a large percentage of "average" people, who will not be able to find new jobs. The author however does not specify whether his notion of "average" refers to occupations, education or general skills.

Overall, this strand of literature mainly predicts jobless economies (or a "near-workless world", using Rifkin's terminology). These predictions, however, are generally rather speculative and not evidence-based. By its very nature, the end-of-work literature tries to look into the future and rejects the idea that trends observed in the past offer good guidance. For instance, it rejects the view that many human intelligence tasks, such as driving, cleaning or complex communication, cannot be taken over by computers. The fact that these tasks have not yet been automated by computers is no guarantee that they will not be automated in the foreseeable future. This makes it difficult to test this theory empirically. Moreover, many analysts who publicly voice the end-of-work paradigm in the past decades are not accredited researchers but public activists, political advisors with various educational backgrounds, technology journalists, and software executives.

Notable exceptions are Brinjolfsson and McAfee (2011), who tried to bring the end-of-work discussion closer to economic academic reasoning. They attempt to summarize the arguments brought forward as the eroding effect of digital technologies on employment and welfare, using examples from case studies and descriptive statistics for the US. The authors warn of massive employment losses due to pervasive deployment of ICT in the

³³ Rifkin (1995).

form of robotics, numerically-controlled machines, computerized inventory control, voice recognition and online commerce into all spheres of production. The most alarming message of this study is that faster and cheaper computers are giving machines capabilities that were once thought to be distinctively human, like understanding speech, translating from one language to another and recognizing certain patterns. This would allow automation to rapidly move beyond manufacturing to jobs in call centres, and marketing and sales, which are parts of the services sector and are currently providing most jobs in the developed economies. However, as official statistics show, low unemployment levels in the US since the 1980s has done much to discredit fears of displacement due to ICT, and it has not been featured in the mainstream discussion of today's jobless recovery.

The main argument used in the end-of-work literature to explain massive layoffs in the developed economies is spectacular technological progress in computers and software that makes it possible to replace virtually all types of jobs performed by humans. This argument has been criticised by two leading economists, Levy and Murnane (2004), who analyzed the capabilities of computers and human workers and delimited the ability of ICT to substitute human workers. According to the authors, computers proved to be excellent in performing tasks within a job that can be expressed in rules, i.e. the ones that follow "if-then-do" algorithm. However, artificial intelligence is not yet able to mimic human abilities in complex pattern recognition and expert thinking, which characterize jobs at both ends of wage distribution.

Both proponents and critics of the end-of-work framework seem to agree on the fact that ICT is affecting the mix of jobs, the changing demand for skills in the digital era, and income distribution. Among the winners and losers that ICT-induced economic changes create, Brinjolfsson and McAfee (2011) define three overlapping sets: high-skilled vs. low-skilled workers, superstars vs. everyone else, and capital vs. labour. While the last two sets of winners and losers are more the subject of welfare studies, the employment dynamics of high-skilled versus low-skilled workers lies well within the boundaries of our report and will be addressed in more detail later in this Chapter.

Skill-biased technological change

Besides the more speculative end-of-work literature there is a more empirically oriented economic research literature that looks at the interaction between technological innovation and the demand for different types of skills.

The increase in demand for specialised skills in the job market and the growing gap between skilled and unskilled workers both in terms of employment and wages have become important policy issues. These labour market dynamics have given rise to a large body of empirical studies. Many of these papers study the decline in relative employment and wages of less skilled workers in the US labour market (Murphy and Welch, 1992, Bound and Johnson, 1992, Katz and Murphy, 1992, Blackburn et al, 1990). Others have revealed similar trends in other OECD countries (Freeman, 1998, Freeman and Katz, 1994, Katz and Revenga, 1989, Katz et al, 1995, and Machin, 1996). Furthermore, there is empirical evidence of these trends going beyond Anglo-Saxon labour markets (Berman et al, 1998, Haskel and Slaughter, 2002, Machin and Van Reenen, 1998, Goos et al, 2009).

The starting point of the theoretical discussion that supports the above empirical findings is the observation that returns to skills³⁴ have shown a tendency to increase over time despite

³⁴ Usually measured by the relative wages of college graduates compared to the high school graduates.

the large increase in the relative supply of college graduates over the few decades. Since wages are determined by the supply and demand of labour, this observation suggests that, alongside the increase in the supply of skills, there has been an even larger increase in the demand for skills. These views, which are high on contemporary policy and research agenda, are not particularly new - Tinbergen (1974, 1975) linked the relative demand for skills to the technology, and thus originated the skill-biased technological change (SBTC) discussion. He emphasized that the return to skills is determined by a race between the increase in the supply of skills and technology-induced demand for skills.

Proponents of the SBTC hypothesis argue that shifts in labour demand towards skilled labour are caused by the impact of technological change and informational technologies which, by definition, are biased towards more highly-educated workers (Machin et al, 1996, Haskel and Slaughter, 2002, Bound and Johnson, 1995, Berman et al, 1994 and 1998, Autor et al, 1998). The SBTC hypothesis argues that increased specialization and growing employment in skilled-intensive jobs occurs within rather than between industries. This approach in explaining the growing divergence of labour markets into high and low skilled workers is mainly supported by labour economists and is based on a combination of four findings (Berman et al, 1998):

- 1) employment shifts to skill-intensive sectors seem too small to be consistent with explanations based on product demand shifts, such as those induced by trade, or Hicks-neutral, sector-biased technological change (Bound and Johnson, 1992, Katz and Murphy, 1992, Freeman and Katz, 1994);
- 2) despite the increase in the relative cost of skilled labour, the majority of industries have increased their ratio of skilled to unskilled labour (Bound and Johnson, 1992, Katz and Murphy, 1992, Lawrence and Slaughter, 1993);
- 3) there appears to be a strong, within-sector correlation between indicators of technological change and increased demand for skills (Autor et al, 1998, Machin, 1996, Machin and Van Reenen, 1998);
- 4) some innovations lower, or are expected to lower, production labour requirements (Mark, 1987).

As comprehensively summarized in Acemoglu and Autor (2011), these ideas have been operationalized by a model that includes two skill groups performing two distinct and imperfectly substitutable tasks.³⁵ Technology is assumed to take a factor-augmenting form, and thus complements either high or low skilled workers. Changes in this factor-augmenting technology then capture skill-biased technical change. This model is not only tractable and conceptually attractive, but it has also proved to be empirically quite successful.³⁶

The SBTC literature is predominantly represented by the empirical studies that demonstrate that most changes in demand for labour occur because of the within-industry skill upgrading due to the technological progress. Berman et al (1994) capture the increased demand for skilled labour by decomposing the changes in labour demand into between-industry shifts (attributed to trade) and within-industries shifts (attributed to technological change). They found that the latter accounts for the bulk of observed skill upgrading. They

³⁵ It is possible to extend the model to include more than two skill groups, like, for example, in Card and Lemieux (2001) and Acemoglu et al (2001).

³⁶ Among others, Katz et al (1995), Davis (1992), Card and Lemieux (2001), Fitzenberger and Kohn (2006), Atkinson (2008), show that it successfully accounts for major cross-country differences among advanced nations.

used investments in computers and R&D expenditure as indicators of technological change. Applied to the US data at the four-digit level of manufacturing industries, their estimates show that computerisation had a statistically highly significant positive coefficient. Taken alone, it accounts for 40% cent of the shift in the wage bill share, while taken together with the R&D variable it accounts for 70% of the move away from production labour. Similar industry-level findings were reported in Autor et al. (1998) and Berndt et al. (1992), both using the US data. Autor et al (1998) proxied technological change by employee computer usage, computer capital per worker, and the rate of computer investment. They find that these indicators are higher in the industries with more rapid rates of skill upgrading in 1970s-1980s. Their estimates indicate that the growth in the computer investment ratio can 'explain' approximately one-third of the increase in within-industry skill upgrading in U. S. manufacturing from the 1970s to the 1980s, while increased rate of computer investment per worker can account for almost 40% of the increase in the rate of skill upgrading from the 1960s to the 1970s and predicts further increase in the 1980s. The impact of computer investment on skill upgrading remains strong (using both contemporaneous and lagged computer investment measures), similar in the manufacturing and nonmanufacturing sectors. Berndt et al. (1992) relates investments in high-tech information technology capital to the distribution of employment by occupation and by level of education. They find that increases in high-tech composition of capital are positively related to skill upgrading and to the growth in white collar, non-production worker hours for twenty two-digit industries in 1968-1986.

The SBTC hypothesis was also confirmed in the firm-level studies that applied richer measures of technology and/or more advanced econometric methodology. Thus, Haskel and Heden (1999), using both industry-level and firm-level panel data sets showed that most of the aggregate skills upgrading in the UK was due to the up-skilling within continuing establishments and can be attributed to computerisation. Computerisation effects are shown to be significant even after controlling for endogeneity, human capital upgrading and technological opportunity at the industry level. Similarly, Dunne et al (1996) applied a decomposition of aggregate change in the share of non-manuals in total employment to the US micro-data, and found a quantitatively significant role for within-firm skill upgrading, which is correlated with two different ICT technology adoption measures, information and production technologies.³⁷ Machin (1996) used two cross-sections of 398 UK establishments and found a positive effect of a computer investment dummy on the employment share of high-skilled workers.

Despite the SBTC model's conceptual and applied virtues, recent labour market dynamics related to technological developments made many argue that it is insufficiently nuanced to account for the rich relationship between skills, tasks and technologies.

The main limitation of SBTC is that it focuses on the impact of technology on skills which are measured exclusively by "education", ignoring differences in the pace of technological changes across jobs and industries. More precisely, the model does not include a meaningful role for "tasks" and equates them with "skills". A task is a unit of work activity that produces output, and is different from a skill, which is a worker's capability to perform

³⁷ The eight information technologies are: computer aided design (CAD), CAD controlled machines, digital CAD, technical data network, factory network, intercompany network, programmable controllers, computers on the factory floor. The eight production technologies are: flexible manufacturing system/cell, materials working lasers, pick/place robots, other robots automatic storage/retrieval system, automatic guided vehicle systems, automated sensor based inspection and/or testing equipment used on incoming or in process materials, automated sensor based inspection and/or testing equipment used on final product.

various tasks.³⁸ In other words, skills are applied to tasks to produce output. This distinction becomes particularly relevant in the ICT era, when workers of a given skill level can change the set of tasks that they perform in response to changes in technology and organization of production.

Another limitation of the SBTC framework often cited by its critics is that it only marks the correlation between technological change and labour demand, without explaining the cause or mechanism. In other words, it treats technology as exogenous and typically assumes that technical change is, by nature, skill-biased. Documented evidence, however, suggests that the extent of skill bias has varied over time and across countries.³⁹

Task-based framework and polarization

Some of the limitations of SBTC have been tackled by Autor et al (2003, 2006), Goos et al (2009), and Autor and Dorn (2010) who argue for a nuanced way of understanding the impact of technology on the labour market, pointing to a more subtle impact of technology on labour demand for different jobs.

Instead of simply splitting the labour force into two groups of high and low skilled workers, the authors analyzed the job content of skills by measuring the tasks performed in those jobs, rather than the educational credentials of the workers performing the tasks. A task-based framework analyzes the allocation of skills to tasks and studies the effect of new technologies on the labour market.

The main finding of the task-biased technological change hypothesis is that technology can replace human labour in routine tasks (both routine cognitive and routine manual activities) but cannot do so in non-routine ones (problem solving and complex communication activities, driving, cleaning). Given that routine and non-routine tasks are imperfect substitutes, it implies measurable changes in the task composition of jobs, which has been tested empirically. This finding is of course coming under pressure in the light of recent technological developments in the ICT sector such as self-driving cars, robots that perform a variety of human tasks and communication robots. These latest technologies have not yet appeared in the statistics.

The task-based framework illustrates how demand for workplace tasks responds to an economy-wide decline in the price of ICT capital. The authors show that industries and occupations that are initially intensive in labour input for routine tasks make larger investments in technological innovations (ICT capital), reducing labour input for routine tasks (which computers can substitute) and the increasing demand for non-routine task input (which computers complement). As a result, relative demand for highly skilled workers, who hold a comparative advantage in non-routine versus routine tasks, increases.

According to the task-based framework, technology substitutes those routine tasks (such as manual crafts, clerical tasks, bookkeeping, etc.), which are normally remunerated with average wages. At the same time, technological changes trigger demand for workers performing non-routine tasks which are complementary to computerization and other innovations. This means an increase in relative demand for jobs requiring professional and managerial skills, which tend to be in the upper part of wage distribution. But there are also

³⁸ Acemoglu and Autor (2011), Autor et al (2003).

³⁹ For example, Autor et al (1998) point at the acceleration in skill bias in the 1980's and 1990's; Goldin and Katz (2008) presents evidence that manufacturing technologies were skill-complementary in the early XX century, but were skill-substituting earlier; Acemoglu (2002) suggested that technology responds to labour market conditions.

non-routine manual tasks which correspond to the lowest paid jobs, like cleaning and driving. Technological innovations so far do not directly affect such jobs but provide an indirect impact through changes in the former two employment groups.

Hence, according to the task-based hypothesis, technological changes provide the following impact on labour demand: a considerable increase in relative demand for better paid highly skilled professional and managerial jobs (non-routine cognitive skills complementary to technological progress), a smaller increase in relative demand for low paid unskilled jobs (non-routine manual skills which are indirectly affected by technological progress) and a decrease in demand for the middle paid jobs which require routine skills (either manual or cognitive work that is usually substituted by technology). Adopting the terminology of Goos and Manning (2007), this process is called “job polarization”: polarization of employment into high and low paid jobs at the expense of middle paid occupations.

Goos and Manning (2007) used data on employment in the UK between 1975 and 1999 and documented job polarization into low and high paid jobs using all measures of employment, for men and women jointly and separately and for different definitions of “jobs”. Moreover, they contrasted results obtained from the task-based hypothesis with the method of wage percentile measurement of employment changes used by Juhn et al (1993) and Juhn (1999) and obtained results which supported the job polarization hypothesis.

Autor, Katz and Kearny (2006) carried out similar research on the US labour market and also revealed an employment polarization into high wage and low wage jobs at the expense of traditional middle wage jobs. Based on the task-based model, they developed a model of computerization in which computers complement non-routine cognitive tasks, substitute routine tasks, and have little impact on non-routine manual tasks.

While both studies revealed a job polarization in Anglo-Saxon economies, Goos et al (2009) have arrived at a similar conclusion for the EU labour market. The authors document the change in the share of overall employment accounted for by three sets of occupations grouped according to average wages into low-, medium-, and highly-paid jobs in each of 16 EU countries during the period 1993-2006. In all 16 countries, middle-wage occupations declined as a share of employment with the largest declines occurring in France and Austria (by 12 and 14 percentage points, respectively) and the smallest occurring in Portugal (1 percentage point). The unweighted average decline in middle-skill employment across countries is reported at 8 percentage points.

Another study, by Stehrer et al (2009), considered the whole set of the EU Member States and concluded that, in terms of polarization, the experience of the EU15 countries and the new Member States over the period 2000-2005 was markedly different. According to their findings, the pattern of employment growth in the EU15 countries shows polarization in the growth of jobs at the top and bottom of the wage ranking. In the new Member States, on the other hand, in sharp contrast to the experience in the EU15 countries, growth in jobs in the middle of the wage distribution was several percentage points higher than at the top, while jobs in the bottom wage quintile slightly declined in number.

A new (still unpublished, but already widely cited by the media) study by Jaimovich and Siu (2012) links job polarization to the slow rebound in aggregate employment following recent recessions, despite relative recoveries in aggregate output. They show how job polarization relates to the jobless recovery by making the two following observations. First, job polarization is not a gradual process; essentially all of the job losses in middle-skill

occupations occur in economic downturns. Second, jobless recoveries in the aggregate are due to jobless recoveries in the middle-skill occupations, which are disappearing.

More speculatively, a recent study (Beaudry et al. 2013) looked at the jobless recovery in recent years and suggested that job polarization can no longer characterise the employment dynamics. Analysing the US labour markets, they offered a novel interpretation of the current employment situation and called it "de-skilling". In particular, they argue that in about the year 2000, the demand for skills underwent a reversal, even as the supply of high education workers continues to grow. They also showed that, in response to this demand reversal, high-skilled workers have moved down the occupational ladder and have begun to perform jobs traditionally performed by lower-skilled workers. This de-skilling process results in high-skilled workers pushing low-skilled workers even further down the occupational ladder and, to some degree, out of the labour force all together.⁴⁰

Globalization vs technology debate

A conceptually different but equally popular hypothesis, put forward to explain the recent widening of the employment and wage gaps between low and highly skilled workers, is the globalization approach. Like the SBTC and task-based approaches, these hypothesis point to factors that cause an upwards shift of labour demand towards skilled workers, which is not matched by an equally large increase in the supply of these workers, but derives from the international trade literature.

Advocates of the globalization hypothesis explain shifts in labour demand as being due to growing international trade integration between advanced economies and low-wage countries. The papers supporting the globalization framework are motivated by neo-classical trade theory, especially the Heckscher-Ohlin model. According to standard Heckscher-Ohlin theory, labour demand has shifted in favour of skilled workers in high-wage economies. The globalization hypothesis assumes that stronger exposure to trade and increasing openness may raise the share of skilled labour, creating more demand for better paid skilled workers and less demand for poorly paid unskilled workers.

The view that the main cause of the increased complexity of skills required for jobs in developed countries is an expansion of trade with developing countries was advanced and developed by Wood (1991a, 1991b, and 1994), Batra (1993) and Leamer (1993, 1994). They put forward the idea that increased goods market competition induces domestic firms to bias innovations towards skilled labour in order to reduce the future threat of imitation or leapfrogging by developing countries.

According to this theory, in particular, growing import competition would increase the proportion of skilled workers in the labour market due to outsourcing and shifts to more skilled-labour intensive activities. For this reason, it is predicted that shifts to more skilled labour will mainly take place due to changes in product demand, and, hence, mostly across industries. Globalization studies that assess employment dynamics both theoretically and empirically can be divided into two unequally represented groups.

On the one hand, the majority of globalization studies that assess skills distribution across countries look at economies at different levels of development (South-North models) and have different factor endowment and technological capabilities (Egger and Falkinger (2003), Kohler (2004), Baldwin and Robert-Nicoud (2010), Grossman and Rossi-Hansberg

⁴⁰ Beaudry et al, 2013.

(2008) and many others). We cannot help but notice that these studies have been widely criticised by the globalization sceptics, who argue that the benefits of globalization are outweighed by job losses, lower earnings for workers in "Northern" countries, and a potential loss of technology to foreign rivals. Wood (1994) has made a case for trade having a huge negative effect on both European and American job markets. In response to this critic, a number of studies show that the job losses in the "Northern" countries cannot be directly linked to off-shoring and outsourcing. For example, the World Bank (1995) claimed that the net effects of trade with developing and transition economies do not seem large enough to account for the massive shifts in labour demand that have occurred within the OECD. Similarly, a recent study by Linden et al (2011) sheds light on the job losses issue by analyzing the iPod, which is manufactured offshore using mostly foreign-made components. In terms of headcount, they estimate that, in 2006, the iPod supported nearly twice as many jobs offshore as in the US. Moreover, the total wages paid in the US amounted to more than twice as much as those paid overseas, which can be explained by the fact that Apple keeps most of its R&D and corporate support functions in the US, providing thousands of highly-paid professional and engineering jobs. This case provides evidence that innovation by a "Northern" company at the head of a global value chain can benefit both the company and "Northern" workers.

On the other hand, only a few papers look at task trade between industrialized countries (North-North). Thus, Hummels, Ishii, and Yi (2001) suggest that North-North specialization is the most common form of vertical specialization in world trade. Additionally, the data reported in WTO and IDE-JETRO (2011) show that intra-European and European-North American trade accounts for a large share of trade in intermediate goods. Motivated by the above studies, and highlighting the production-sharing arrangements of Boeing 787 Dreamliner,⁴¹ Grossman and Rossi-Hansberg (2012) developed a theoretical model of trade in tasks (i.e. off-shoring) between countries that have exogenous sources of comparative advantage but differ in size. To our knowledge, this model has not been applied to data in order to produce the evidence of employment effects of off-shoring between developed countries. At the same time, several polarization studies (as described in the previous section) have looked at the dynamics of task composition within countries (for example, Autor et al, 2003 for the US, and Spitz-Oener, 2006, for the German data) and have found that, since the 1980s, the countries under investigation have specialized more in tasks that are non-routine interactive and/or analytical and non-routine manual. We believe that application of the Grossman and Rossi-Hansberg model in combination with the polarization approach may shed light on the role of vertical integration and off-shoring between developed countries in employment dynamics.

There is an on-going discussion on the advantages of the globalization framework (supported mainly by trade economists) versus the skill-biased technological change framework (favoured by labour economists) to explain the observed employment dynamics in developed economies. The difficulty in the trade versus technology debate is how to disentangle the effects of technological changes from the effects of globalization, which is a theoretically and empirically complex task. Nonetheless, there have been several attempts to combine the two approaches in order to evaluate the relative importance of each (see, for example, Feenstra and Hanson, 1999 and Feenstra 2007). Yet, when fit to

⁴¹ Boeing relies heavily on local expertise when making its sourcing decisions: the wings are produced in Japan, the engines in the United Kingdom and the United States, the flaps and ailerons in Canada and Australia, the fuselage in Japan, Italy, and the United States, the horizontal stabilizers in Italy, the landing gear in France, and the doors in Sweden and France (Grossman and Rossi-Hansberg, 2012).

data, such attempts provide ambiguous results as regards the relative importance of technology versus globalization and the magnitude of their effect on employment. In empirical studies, most authors have tried to extract first the globalization effect and then attribute the residual to technological progress. Berman, Bound and Griliches (1994) put forward a framework that allows them to distinguish between the two effects. Relative demand for skilled workers may rise because skill-intensive industries are gaining shares whereas low-skill-intensive ones are losing shares (between industry shifts, or a sector bias). It could also be that relative demand for skilled workers is rising within the industries (within industry shifts or a factor bias). The first effect would be expected if trade specialization in a Heckscher-Ohlin framework matters, the second would be expected in the case of skill-biased technical progress (Stehrer 2004). Using data on manual and non-manual workers, Berman, Bound and Griliches (1994) showed that within-industry shifts are much more important than between-industry shifts. From this, it was concluded that technology mattered far more than trade. This result was confirmed by other empirical studies (Borjas and Ramey, 1994, and Bound and Johnson, 1992 Berman et al., 1998, and Berman and Machin, 2000).

Though both frameworks depart from distinct sets of assumptions and use different methodological tools, we believe that they need not necessarily be rivals in explaining the employment dynamics of the last few decades. As Freeman (2009) puts it, “offshoring and digitalisation go together”. On the one hand, advances in ICT lie behind globalization as they improve the way information is shared and facilitate efficiency gains (for example, through up-to-date digital systems of enterprise resource management or customer relationship management). On the other hand, globalization enables ICT progress through various channels of international competition, ranging from off-shoring and outsourcing (cost competition) to competing on technology-enabled products and processes (technological or Schumpeterian competition). A good example of the possible consensus between technology and globalization approaches is put forward in a theoretical study by Acemoglu et al (2010). This study illustrates the employment effects of a combination of ICT progress (through innovation) and globalization (through standardization of production processes). The model used in this study suggests that while (product) innovation increases the demand for skilled workers, standardisation alleviates the demand pressure on scarce highly-skilled labour by shifting some technologies to low-skilled workers, thereby raising aggregate labour demand and fostering incentives for further innovation.

Task-based models with endogenous technological change and labour supply, trade and off-shoring

All the frameworks described above model the changes in labour demand for tasks/skills using either technology or trade as the main driving force behind these changes, and have merits in specific aspects of complex economic reality. Such argumentation is however partial-equilibrium in nature: focussing on technology or trade it abstracts from interaction between labour and product markets, and leaves behind such important factors that influence employment dynamics as, for example, population ageing or shifts in quantity and quality of labour supply. Moreover, because it treats technical change as exogenous, it is also silent on how technology might respond to changes in labour market conditions and in particular to changes in supply of specific skills.

Ideally, an empirical researcher would seek for a comprehensive framework capable of encompassing the whole set of the main factors that are shaping employment dynamics.

One framework of this kind has been recently developed by Acemoglu and Autor (2011). It builds on Acemoglu and Zilibotti (2001) and Costinot and Vogel (forthcoming). To a certain extent, this model relates to the trade literature, particularly in the context of outsourcing and off-shoring.⁴² This nuanced framework consists of a continuum of tasks, which together produce a unique final good. Each worker is assumed to be endowed with one of three types of skills: low, medium or high. As in the Ricardian trade model, workers have different comparative advantages. Given the prices of different tasks and the wages for different types of skills in the market, firms and workers choose the optimal allocation of skills to tasks. Technical change in this framework can change the productivity of different types of workers in all tasks (in a manner parallel to factor-augmenting technical change in the SBTC model) and also in specific tasks (thus changing their comparative advantage). The model treats skills (embodied in labour), technologies (embodied in capital), and trade or off-shoring as offering competing inputs for accomplishing various tasks. Depending on a cost and competitive advantage, each input (labour, capital, or foreign inputs supplied via trade) is applied in equilibrium to accomplish different tasks. Relative wages of high to medium and medium to low skill workers are determined by relative supplies and task allocations. The SBTC model can be seen as a special case of this general task-based model.

Even though the above framework allows for an increasingly richer interaction between technology and wages compared to the above described model, Acemoglu and Autor (2011) show that it is tractable empirically. Endogenously changing allocation of skills to tasks suggests the richer implications of this model. Notably, while factor-augmenting technical progress always increases all wages in the canonical model, it can reduce the wages of certain groups in this more general model of Acemoglu and Autor (2011). Moreover, it allows for different forms of technical change, in particular the introduction of new technologies replacing workers in certain tasks, and thus has richer but still intuitive effects on employment patterns. An extension of the model that allows the supply of skills and technology to be endogenised is especially valuable for policy application.

The authors show how the mechanisms proposed by the task-based model with trade and off-shoring suggest new ways of analyzing the data and provide some preliminary empirical evidence resulting from this approach.

Jung and Marcenier (2011) drop the partial equilibrium setting and propose a simple two-sector general model with heterogeneous labour and imperfectly competitive firms that make explicit offshore outsourcing decisions. They investigate the effects, on the wage and the employment distributions, of alternative potential causes that have been proposed in the literature: a task-biased technical change, the globalization of the world economy, shifts in preferences due to population ageing, and changes in the quality of the labour supply. Their theoretical discussion leads to a rejection of the latter three candidate explanations, and concludes that task-biased, or more specifically routinization-biased, technical progress is the only one that seem to be able to reproduce the stylized facts: rising employment shares at the two extremes of the skill ladder, and monotonously rising average wages with the skill intensity of occupations.

⁴² Feenstra and Hanson (2005), Grossman and Rossi-Hansberg (2008), Rodriguez-Clare and Ramondo (2010), and Acemoglu et al (2010).

4. Further perspectives of employment impact of ICT

Though compensation and substitution theories differ in their fundamental assumptions and draw somewhat different conclusions, most researchers now agree on a range of theoretical and empirical aspects of the employment impact of ICT. These aspects are briefly presented below.

Multi-channel effect of ICT on employment

Both theoretical and empirical researchers now agree that from the macroeconomic perspective, the employment impact of ICT can be direct, through growth of the ICT-producing sector, and indirect through multiplier effects and externalities that take place in the ICT-using sectors.⁴³ The dynamic character of the ICT-producing sector is transmitted into the rapid employment expansion of new firms in these industries. New entrants in the ICT sectors – if they survive – grow much more rapidly than firms in other parts of the economy. The picture is less clear when one looks at the ICT-using sectors. Here, the employment effect of ICT may depend, for instance, on whether product or process innovations are deployed. It may also depend on whether ICT-induced productivity translates into employment growth through increased consumption out of labour income, or increased variety of goods and services.

Moreover, some authors⁴⁴ point at a third type of the ICT effect on employment – effects on market structure of qualitative and quantitative nature, that influence the type of employment on demand, the skills required and even the labour market configuration.

An example of the multi-channel effect of ICT on employment is well illustrated in a study by Katz (2009). It shows that broadband penetration can increase employment in at least three ways. The first is the direct effect of jobs created in order to develop broadband infrastructure, the second is the indirect effects of employment creation in businesses that sell goods or services to businesses involved in creating broadband infrastructure, and the third is induced effects in other areas of the economy. The latter two ways can be expressed, through an input-output model, as multiplier effects. The relationship between broadband diffusion and employment through these mechanisms is a causal one, although the estimate of employment growth relies on a number of assumptions.

While empirical analysis can take into account all the direct and indirect effects of ICT, it is often severely constrained by the difficulty to quantify the final impact of ICT on employment. This difficulty is mainly related to construction of proper aggregate proxy of ICT-led innovation and by the existence of the whole range of determinants of changes in employment trends that are unrelated to technological progress. Among the latter are the macroeconomic and cyclical conditions, the labour market dynamics, the institutional characteristics of a country or a sector of economy (like, for example, prices, wages and property rights regulations), the trends in working time and so on.⁴⁵

Several studies undertook the attempt to capture the multi-channel effect of technology on employment by departing from the assumption that the ICT-induced innovation and other determinants of job creation and loss have the same impact across industries. One of the most cited approaches is the one suggested by Pavitt (1984) who classified industries in

⁴³ In real life ICT-producing and ICT-using sectors are not necessarily mutually exclusive notions and may well characterise one given sector that both produces and uses same or different ICT.

⁴⁴ Haltinwanger et al (2003).

⁴⁵ Vivarelli (2012).

four groups on the basis of the nature of technological change, the features of production processes, market structures and other characteristics. Bogliacino and Pianta (2010) further developed this approach by extending the original Pavitt groupings to include services. They developed a model that describes the relationship between technology and jobs where employment changes are explained by innovation, demand, wages and other factors, and tested it on the sectorial data from the Sectoral Innovation Database (SID)⁴⁶ matched to the EU KLEMS data for eight European countries, Germany, France, Italy, Norway, the Netherlands, Portugal, Spain and the United Kingdom. They found that the expansion of hours worked in Science-Based industries over the period of study is driven by the relevance of new products and by the net entry of new firms; in Specialised Supplier industries, where the best job-creation performance is observed, different mechanisms affecting jobs coexist with weaker positive effects of new products and stronger negative effects on new labour saving processes, with a positive impact of demand and a negative one of wages; in Scale and Information Intensive sectors (that recorded a net loss of jobs) employment changes are dominated by a labour saving use of technology and by a strategy of cost competitiveness, with a positive role of demand, a negative effect of wages and with no relevance of industrial dynamisms (given their oligopolistic market structure); finally, Supplier Dominated industries (that also experienced a decline in employment) show that changes in hours worked are the result of the negative effect of new processes (reflecting a search for cost competitiveness) and wages while the increase in demand is the only factor supporting job creation in this group.

Product and process innovation

A key convention in the literature on the employment effect of innovation in general and of ICT in particular draws a distinction between product innovations (which affect the demand for the firm output) and process innovations (which influence the production function). A theoretical discussion on this topic can be found in the works of Nickell and Kong (1989), Van Reenen (1997), Garcia et al (2002), Harrison et al (2005), Vivarelli (2012). Analysis has tended to focus on the latter rather than the former, perhaps because of the view that product innovations will always be associated with higher employment since new products will generate new consumer demand and should increase labour demand. In practice, the distinction between the two types of innovation is not always clear, since process innovation often accompanies product innovation and vice versa. Harrison et al (2005) in their empirical study on the employment effect of innovation suggests that both types of innovation can be interpreted as the random result of the firm's investment in R&D and other innovative activities.

Taking manufacturing and services jointly into account (using CIS cross-sectional sectoral data on relevant innovations for eight European countries, for the period 1996-2004), Pianta and Bogliacino (2010) find a positive employment impact of product innovation (against a negative one of process innovation). Finally, Bogliacino and Vivarelli (2011) analysing panel of 25 manufacturing and service sectors for 15 European countries over the period 1996-2005 find that product innovation is associated with a job-creating effect.

By investigating the employment effects of both product and process innovation at sectoral level in five European countries (Denmark, Germany, Italy, the Netherlands, and Norway) from 1990-1992, Pianta (2000) concluded that job losses in most industries tend to be heavier in the sectors with higher innovative intensity, suggesting that the dominant effect

⁴⁶ Developed at the University of Urbino.

of overall innovative efforts has been to displace labour (see Table 3). He also looked at the determinants of changes in employment in product- and in process-oriented industries separately for the period 1974 to 1994 in order to test whether different employment outcomes resulted from the different orientation of national innovation and production systems. The main result of this analysis was that, in all countries, employment change (negative for the UK, France and Italy and positive for Germany, the US and Japan) has always been greater in product-oriented industries than it has in process-oriented industries. This is an important finding since the product-oriented industries are associated with the shape of employment performance in the long term (because of the market expansion and job creation potential). As far as process-oriented industries are concerned, technological unemployment is found in all countries, which suggests that compensation mechanisms do not operate within the boundaries of this group. Both results support the idea that the structural composition of industry is important in shaping overall employment outcomes.

Table 3: Determinants of employment change in 21 manufacturing industries in Denmark, Germany, Italy, the Netherlands and Norway

	1	2	3
<i>Change of value added</i>	0.49***	0.49***	0.48***
<i>Total innovation expenditure per employee</i>	-2.45E-07**	-2.27E-07**	-2.06E-07*
<i>Share of R&D related to product innovation</i>	0.02*	0.03**	0.02*
<i>Share of new products in sales</i>	-0.02*	-0.03*	-0.02
<i>Share of export in value added</i>	3.01E-05	3.08E-05	
<i>Change of labour costs per employee</i>	-0.21		-0.22
<i>Country effects</i>			
<i>Denmark</i>	-0.02**	-0.03***	-0.2*
<i>Germany</i>	0.002	-0.01	-0.002
<i>Italy</i>	-0.03***	-0.03***	-0.03
<i>The Netherlands</i>	-0.01	-0.02*	-0.01
<i>Norway</i>	-0.05***	-0.05***	-0.05***
<i>Adj. R-squared</i>	0.60	0.60	0.60
<i>F</i>	15.05***	16.23***	16.26***
<i>Number of cases</i>	103	103	103

Note: dependent variable is rate of change of employment; significance levels: * is 90%, ** is 95%, *** is 99%

Source: Pianta (2000)

The approach, which has emerged in the last decades as the most appropriate for obtaining internationally comparable data on product and process innovations is based on innovation

surveys of firms.⁴⁷ This method relies on the answers provided by firms to national questionnaires run by most EU countries in a standardized way since the early 1990s. Firm-level data made it possible to look more precisely at the actual content of innovation based on ICT utilization by looking, for example at variables that measure broadband penetration, use of mobile connections, use of ICT for Enterprise Resource Planning, Supply Chain Management or Customer Relationship Management.

Both product and process innovations are (in most cases) associated with increased productivity and translate into changes in labour demand as described below.⁴⁸

The new or improved product may imply a change in production methods and input mix, which could change labour requirements. Though the extent and direction of this effect must be determined empirically, many studies find that the most important outcome of product innovation is likely to be positive compensation effects resulting from increased demand for the firm's product. The channel through which this compensation effect transmits into changing labour demand depends on the nature of competition on the product and labour markets, as well as on the delay in the competitors' reaction.

Any increase in productivity resulting from a process innovation implies a reduction in unit cost. Process innovations tend to displace labour because pure process innovations are likely to reduce the quantities of factors required to obtain a unit of output. The size of this effect will depend on whether process innovation is labour or capital augmenting, and on the competitive conditions facing the firm. Depending on the business context, the actual effect on employment may well be positive: if process innovation leads to a lower price, it will stimulate demand, which can be turned into higher output and employment depending on the elasticity of demand for firm's products (in line with compensation effects described in Chapter 2).

Measurement approaches: levels of aggregation

From an empirical point of view, the employment impact of ICT can be rather resistant to measurement.⁴⁹ Technological change in general and ICT diffusion in particular are difficult to capture in data: traditional indicators such as R&D, patents and relevant innovations are seldom completely reliable at the macro level and are often unable to represent fully technological change at the level of the entire economy. Moreover, the employment impact of ICT-induced technological and organizational innovations depends on economic and institutional mechanisms such as macroeconomic and cyclical conditions, labour market dynamics and regulation, trends in working time and so on. This leads to a situation where the relation between ICT and employment can differ deeply across countries and sectors, even within economically integrated blocks like the EU. In some economies, labour-friendly product innovation can prevail, while in others labour-saving process innovation can dominate, and the net effect on employment is determined by a particular mixture of regulating institutions.

Approaches to study the relation between ICT and employment have been undertaken at different levels of aggregation – macro, sector, and firm levels – which allows unveiling different aspects of this relation.

⁴⁷ Pianta (2000).

⁴⁸ See more on the relation between ICT-induced innovations and firm productivity (also in relation to organization and human capital) in Biagi (2013).

⁴⁹ Sinclair (1981); Layard and Nickell (1985).

Macro level

Studies on computerised technological change and employment at the aggregate level include Freeman and Soete (1994), Machin and Van Reenen (1998), Simonetti, Taylor and Vivarelli (2000), Autor, Katz and Kearny (2006), Goos et al (2009) and others.

Most of them arrive at similar conclusions on the macroeconomic effect of technological change and employment, and the role played by ICT:

- a) in the long term, moderate employment creation in Europe contrasts with marked job creation in North America;
- b) though the diffusion of ICT led to jobless growth and negative employment elasticities in manufacturing, a different pattern emerges in services;
- c) long-term evolution must be distinguished from short-term correlation;
- d) Europe differs structurally from North America in their job creation capacity, which is especially marked in the long term;
- e) an economically and statistically significant positive correlation between ICT and employment is found for the share of highly skilled workers, though it tends to decrease for medium-skilled occupations; low-paid jobs show slightly increasing growth in most developed economies.

Empirical contributions to the literature on technology and employment at the macroeconomic level usually adopt one of the following three methodological approaches: input-output models that specifically look at ICT (Leontief and Duchin 1986, Whitley and Wilson 1987, Kalmbach and Kurz 1990, Meyer-Krahmer 1992, Katz and Suter 2009, Katz et al 2010, Rohman and Bohlin 2010), tests of the compensation mechanisms validity using partial and general equilibrium frameworks (Layard and Nickell 1985, Nickell and Kong 1989), and models testing the direct relationship between growth and TFP on the one hand and employment on the other by looking at employment elasticities (Boltho and Glyn 1995, Padalino and Vivarelli 1997, Piacentini and Pini 2000).

One of the main empirical challenges faced by macro-modellers is finding a reliable proxy for the ICT-induced technological growth. Depending on the data available and on the proxy used, different employment effects may surface. A good example of this ambiguity in estimating outcomes is a study by Severgnini (2009), who contrasted a set of basic and augmented specifications commonly employed in empirical studies of labour demand and applied them to data within and across European and non-European countries. Depending on the variable that captures ICT progress, the effect on employment is highly dispersed around a small negative number and rarely significant. When a general measure of technology is considered, technological change usually has a negative short-term and a positive long-term effect on employment in the most important industrial countries and in the EU15 as a whole. On the other hand, when a direct measure of ICT (the ratio of ICT investment to output) is included in the specification, new technologies can present different signs in both short and long-term effects. If a measure of total factor productivity contributed by ICT is considered, technology seems to have a general negative impact on employment. These results suggest that ICT can have either a labour-saving effect, or stimulate employment. However, all models regardless of how they proxy ICT progress show that employment outcome is positively affected by output, negatively affected by wages, and depends on the particularities of the country, including the supply of labour, and product and labour market institutions.

Neither the literature on ICT and employment nor macroeconomic studies offer a precise and robust model that can capture the net employment effect of ICT and ICT-enabled innovations, theoretically or empirically. The main reason for this with regard to the macro-level framework is the complexity of the ICT-employment nexus which has a variety of direct and indirect interconnections. The relation cannot be captured by the partial or general equilibrium, input-output or other macro-models, and is resistant to empirical generalizations.

Sector level

Sector-level data enables the empirical analyses that focus on units of economic activities where relatively homogenous technological regimes and innovation models are adopted (Pavitt, 1984, Malerba and Orcenigo, 1997, Antonucci, Meliciani and Pinata, 2003 and Pianta 2007, Piacenti and Pini, 2000, and others). These studies can spot the overall effect of technological change and can account for its direct impact on innovating firms, and for the indirect effects that operate within the industry, including business stealing effects, product substitution or differentiation, price elastic market expansion, changes in market shares, entry and exit of firms, competition patterns, vertical integration/disintegration, etc. Sector-level studies distinguish between employment effect depending on the sources and patterns of innovation and the forms of their introduction (which are highly sector-specific).

The advantage of the sector-level approach is that it allows us to account for changes in the structural composition of economy, often referred to as *a compositional effect* (which both macro-and micro-approaches fail to do), and to determine the decline or the consolidation of ICT-induced innovations with different consequences for employment. Structural factors of the employment impact of ICT innovations that are considered in sectoral studies include: the role of demand and its dynamics (proxied, for example, by value added⁵⁰), of labour costs and wages dynamics, and of different paces of technological progress, and the extent of commitments towards product or process innovations among sectors.

Sectoral empirical studies have suggested that changes in structure of economy is the driving force behind the employment effect of technology, while the sources and opportunities for both technological innovations and for job creation are specific to individual industries (Malerba 2002, Antonucci and Pianta, 2002, and Bogliacino 2010). Sector-level evidence over the last few decades shows that European manufacturing employment has experienced periods of depressed or negative job growth, generally as a result of weak demand expansion, high wage dynamics, prevalence of labour-saving process innovations and weak product innovation (Vivarelli, Evangelista and Pianta 1996 and Pianta 2000, 2001, Antonucci and Pianta 2002, Antonucci 2003, Evangelista and Savona 2003, Mastrostefano and Pianta 2007). Job losses are usually found in the largest firms, among low-skilled workers, in sectors that are heavy users of ICT, in sectors that are capital-intensive and in those that are related to the financial industry. Job creation usually occurs in sectors with high demand growth and orientated towards product innovation, and in countries that are open economies with a strong presence of highly innovative and rapidly growing markets.

Mastrostefano and Pianta 2007 applied a compositional change perspective to develop a model for testing the evolution of employment in manufacturing industries in 10 industrial sectors in 10 European countries. Their findings reveal the complexities of the determinants

⁵⁰ Antonucci (2007).

of employment change, highlighting the role of different strategies for innovation (product versus. process), of whether a sector is more - or less innovative, and of whether the short-term labour market effects or the longer-term impact of structural change is considered. Piacentini and Pini (2000) used sector-level analysis to investigate how much employment growth derives from changes in the employment composition of each economy, and how much can be explained by absolute sectoral performance. To this end, they broke down aggregate employment change in 5 European countries, the US and Japan into two components, one related to sector growth and another related to sectoral composition changes (see Table 4). The findings suggest that most employment gains in European countries are due to changes in the sectoral composition of the economy, rather than to an absolute higher capacity to create new jobs within sectors. More specifically, it is the increase of the relative share of service sectors with respect to industrial sectors that explains the new job opportunities.

Table 4: Decomposition of employment dynamics in composition and sector effects (%)

<i>country</i>	<i>period</i>	<i>composition effect</i>	<i>sectoral effect</i>	<i>total</i>
<i>W. Germany</i>	1979-95	0.26	0.36	0.62
<i>Italy</i>	1979-95	0.33	-0.15	0.19
<i>The UK</i>	1979-95	0.33	-0.01	0.32
<i>France</i>	1979-95	0.42	-0.20	0.22
<i>Sweden</i>	1979-95	0.28	-0.54	-0.26
<i>The US</i>	1981-95	0.28	1.29	1.57
<i>Japan</i>	1979-95	0.74	0.37	0.11

Source: Piacenti and Pini (2000).

A shortcoming of sectoral analysis is that, unless the whole economy is analysed, it may be negatively or positively biased according to the observation point of view, i.e. technological change can have a negative employment impact in manufacturing industries (Pianta 2000 and Antonucci and Pianta 2002), a positive employment impact in the most innovative and knowledge intensive service sectors, and a negative impact in financial-related sectors and most traditional services like trade and transports (Evangelista 2000 and Evangelista and Savona 2002). Moreover, at the sectoral level, the analysis may not be able to explain all the direct and indirect effects of technological change (Vivarelli 2007).

Micro level

On the whole, firm-level empirical findings suggest that product innovation is clearly associated with employment growth, although the balance between displacement and compensation effects remains unclear. A non-exhaustive list of papers that tackle this subject include Entorf and Pohlmeier, 1991, König et al, 1995, Van Reenen, 1997, Greenan and Guellec, 2000, Garcia et al, 2002, Peters, 2004, and Harrison et al, 2005. Where

process innovations associated with ICT are concerned, micro-analysis reveals effects which range from negative⁵¹ to positive⁵² according to the specification.

Micro-level studies usually face two types of critical argument. The first is that firm-level studies cannot always identify whether the gains of innovating firms are made at the expense of competitors (“the business stealing effect”), or whether there is a net effect on the aggregate industry. Thus, Greenan and Guellec (2000) show that for France, the job-creating effect of process innovation at firm level disappeared when analysis is carried out at industry level. The second critical argument is related to the fact that firm-level surveys are usually not representative of the whole industry or economy. As underlined in Mastrostefano and Pianta (2007), sample selection bias may lead to panels where the presence of innovators is distorted, and this makes comparisons of different studies difficult, and prevents researchers from drawing conclusions on what may happen to an industry as a whole. However, this impediment has been addressed by Eurostat in recent years: the solution could be to use innovation surveys where data can account for total economic activities in the industries concerned (like, for example, the data used in the CIS – the Community Innovation Survey), or to build national and cross-national representative data sets from combining information derived from business registers, production surveys, EU-harmonized ICT usage surveys, the CIS and other sources (like for example the Eurostat Project on ICT Impact and ESSnet on Linking of Microdata on ICT Usage⁵³). Creation of these rich sets of variables makes it possible to account in a more sophisticated and satisfactory way for the complexity of the employment impact of innovations generated by ICT progress.

While firm-level data do not tell us much about the overall employment effect on an industry or a national level, they do confirm the message that innovative firms are the ones that bring job-creating change to the labour market, as opposed to the non-innovators. Moreover, for the sake of the argument, it must be said that although micro-analysis does not relate directly to aggregate employment effects, it provides essential and valuable information on the micro-mechanisms that underlie aggregate employment growth and on the barriers to the job-creating effect of ICT. An essential question, which should be addressed by the corresponding aggregate studies, is to establish what the relative importance of job-creation versus job-destruction at the aggregate level is.

Micro, sector and macro approaches have their merits and drawbacks, and an interesting question is how the employment effects of ICT-induced innovation at the firm level relate to aggregate changes in employment. A direct link between these two perspectives is, however, difficult to establish. Harrison et al (2005) offers two main reasons why the aggregate effect of innovation on employment cannot be directly inferred by multiplying the average firm-level effect by the number of firms. First, the firm-level studies do not distinguish between the market expansion⁵⁴ and the business-stealing⁵⁵ employment effects of innovative activities. If innovation by firms results in business-stealing rather than market expansion, then the aggregate effect of innovation on employment will

⁵¹ Ross and Zimmerman (1993).

⁵² Doms et al (1995) or Blanchflower and Burgess (1999).

⁵³ See Bartelsman and Barnes (2001) and Bartelsman (2004) for a detailed description of the data method.

⁵⁴ When business proximity of economic rivals leads to intense price competition, creating an incentive to locate further from rivals to soften competition.

⁵⁵ When an activity is located close to competitors in order to attract the competitors’ consumers (sometimes also referred to as a *market-share effect*).

generally be smaller (either less positive or more negative) than the firm-level effect.⁵⁶ Secondly, entering or exiting firms cannot always be identified in the micro-data. Firm entry, which may be the result of innovation, is an important source of employment growth, while exit may be induced by successful innovation and business-stealing by rival firms. A full industry-level analysis would have to explicitly incorporate entry, exit and competition between rival firms.

An important concern for policy is that the final employment impact of ICT depends to a large extent on institutional mechanisms which can be very different at the micro, sectoral and macro levels and can vary in different contexts, such as different countries or different sectors within the same country. In order to devise a consistent policy with long-term direct and indirect employment effects on the development and the diffusion of ICT, the level of aggregation needs to be carefully chosen, and, where data allows, a complex study involving different level of aggregation should be carried out. A comprehensive approach of this kind would allow us to distinguish the final employment effect of ICT and any variations according to macroeconomic and cyclical conditions, labour market dynamics and regulation, trends in working time, sector-specific innovation strategies, etc.

⁵⁶ It should be remembered that the average firm-level employment outcomes observed by an empirical researcher already embody the effects of business-stealing by firms' rivals, even if the rivals' identity is not known or not observed in the sample.

5 Conclusions and some policy implications

No unambiguous diagnosis of the employment effect of technological change in the economic literature

Economic theory supported by empirical studies suggests a rich variety of changes in different aspects of employment in response to technological advances in the production and organizational structure of modern economies. However, a comprehensive overall picture remains elusive. By and large, a generalization based on macro-level empirical evidence boils down an unclear relationship between technology and employment to a trade-off between the creation of low-wage employment through downward wage adjustment (as in the US), and growing technological unemployment as a result of automation of routine jobs (as in Europe). However, the picture becomes more complex if one adopts a sector- or a micro-level perspective and tries to distinguish between different innovation types and strategies, and different types of labour.

Compared to the literature on technology and employment in general, the number of empirical studies that specifically focuses on the employment impact of ICT is limited. The relationship between ICT and employment is a complex problem which cannot be entirely solved by simplified equilibrium models or by unfounded empirical generalizations. It is necessary to start from an open-minded theoretical approach, and to try to steadily unveil, represent and estimate the whole spectrum of direct and indirect effects and transmission mechanisms. The right model, assumptions, and data are crucial for generating reliable evidence. The literature offers a wide range of theories and measurement techniques which can be used for assessing the employment effects of ICT.

Compensation or substitution?

Traditionally, two main competing economic theories, compensation and substitution, have influenced economic policies since the previous century.

The substitution framework puts forward the view that the labour-saving effects of technology affect different skills in different ways and thereby cause both positive and negative employment displacement across the skills spectrum. It may lead to job polarization at both the high and low skills end of the spectrum and, in its extreme interpretation, to a jobless economy where computers substitute human intelligence in virtually all occupations. Substitution theories that emphasise the skill-biased effect of technology are mainly empirical and are based on the evidence of a significant change in the composition of the labour force in favour of skilled labour over the last three decades. Nourished by a wealth of data-based evidence, this literature is now rich in solid theoretical foundations and occupies an important place in the academic debate.

The neo-classical compensation theory takes a more aggregate long-term perspective and looks at overall employment displacement without distinction between skills. For decades, compensation theory has pointed out the existence of economic forces, which can (partly) undo the negative labour-saving effect of technological change. This latter view has long sustained policy makers' a-priori confidence in the market as a sufficiently powerful mechanism to compensate employment reductions by new employment creation.

Nowadays, the changing employment landscape characterised by on-going displacement of labour in the economic downturn has further stimulated demand for solid empirical support for policy measures, helped by constant improvements in conceptual models and data.

The emergence of ICT-driven technological change has drawn attention to the structural nature of (un)employment trends and to substitution theories, which sustain that ICT changes the organization of production and alters the very nature of employment. While extreme end-of-work theories seem to have for the time being a much weaker empirical basis, they have done a good job in attracting the attention of policymakers to the polarization of labour markets and the disturbing hollowing out of routine tasks in medium-skilled medium-paid occupations that can be more easily automated than high-skilled and low-skilled tasks. Moreover, a more nuanced task-based economic analysis has started to attract increasing attention. In the view of a polarization hypothesis and a task-based framework, recent employment trends should be seen as indicative of pervasive mismatches between the rapidly changing demand for labour due to ICT-induced innovation in production and consumption, and lagging adjustment in the skill composition of the labour supply at individual and institutional level.⁵⁷

What can economic literature suggest to policy?

Sluggish economic and employment growth in Europe, in combination with a tightening of governments' fiscal space and consequent decrease in social spending, makes the relation between ICT and employment even more critical, and points to a number of important policy questions. Many of them have already been reflected in EC strategies aimed at meeting the employment target set in the *Europe 2020* strategy. In particular the *EU Agenda for New Skills and Jobs*⁵⁸ and *Digital Agenda for Europe*⁵⁹ address the issue of job creation and improvement of job quality, development of digital skills and inclusion of EU citizens. These areas of focus, however, are very generic and economic literature can potentially provide insights that would help determining specific mechanisms of interaction between ICT and employment that can be targeted by policy interventions.

The main policy conclusions that can be drawn from this literature review can be summarized as follows.

(1) Polarisation of employment into high and low paid jobs at the expense of medium-paid ones, has firmly entered the policy debate⁶⁰ and has been extensively documented in the economic literature.⁶¹ This trend has been intensified in the recent economic and financial crisis. The polarisation dynamics coincide with increased demand for high educational and skills profiles, thus compromising the chances of re-employment and access to well-paid jobs for lower-skilled people who became unemployed during the recession. The availability of high-skilled jobs will not transform into better employment outcomes unless national training systems and labour-searching institutions adapt to new needs. This points to one of the issues that polarization theory raises – skills mismatches and adapting the supply of labour to skills demanded in the labour market. As stated in 2012 DG ECFIN's economic forecast,⁶² recovery in employment is held back by skills mismatches. It is thus crucial to improve labour market matching and adaptability of workers to change, at the same time as supporting and developing sectors with sustainable job-creation potential. In line with

⁵⁷ The proponents of this view in economics include, among others, Autor et al (2003 and 2006), Petit and Soete (2001), Pianta (2001), Caroli (2001), Card and Lemieux (2001).

⁵⁸ <http://ec.europa.eu/social/main.jsp?langId=en&catId=958>

⁵⁹ <http://ec.europa.eu/digital-agenda/en/our-goals>

⁶⁰ EC (2012a and 2012c), OECD (2011), and UNESCO (2012) to cite the most recent policy documents.

⁶¹ Autor et al (2003 and 2006), Autor, Katz and Kearny (2006), Goos and Manning (2007), Goos et al (2009), Stehrer (2009), Autor and Dorn (2010), Jaimovich and Siu (2012).

⁶² EC (2012c).

the recommendations of the recent EC, OECD and UNESCO publications,⁶³ this points to issues of more adaptable wage-setting mechanisms, income security implications of low-skilled workers and the need for up- and re-skilling of the workforce at all levels.

The key issue here is how fast education and training institutions can deliver the required skills and whether they can keep up with the pace of change in skills demand in the labour market. An increase in the rate of change in skills demand also lowers the rate of return to educational investments and diminishes the incentive to invest. Moreover, SBTC theory does not guarantee that even a fully matching supply and demand for skills brings us back to full employment. The spectre of work destruction in the EU, raised by compensation theory models, combined with substitution between human and computer skills, keeps hanging over the labour market.

(2) Another issue, closely related to the polarization trends in the European labour markets, is rising income inequality through depressed earnings of the low and middle income groups.⁶⁴ This, inevitably, leads to decreasing demand from a large part of the population. While the majority of studies revised in this paper focus on the supply side of economy (which is linked to the labour demand through different models), a critical and careful consideration of the demand side of the economy is no less important and should not be neglected. Several empirical studies⁶⁵ demonstrated that liberalisation of the labour markets and adverse changes in income distribution to workers tends to affect the composition of aggregate demand by depressing domestic consumption (especially consumption by those in the middle and in the bottom of the skills distribution), demand and, ultimately, employment. At the same time, the very favourable dynamics of labour productivity in recent years, largely boosted by the ICT innovations, has not been associated with similar adjustments in real wages.⁶⁶ As noted in EC (2012a), wages, especially those of low-skilled workers, lag significantly behind productivity developments. Compensation theory touches upon market mechanisms that may offset technological unemployment through stimulating demand, and several authors⁶⁷ point out that employment dynamics related to ICT innovation need to be linked to the dynamics of (different components of) final demand and income distribution. They advocate the view that institutional and distribution systems play an important role in shaping the causal links between productivity, demand for final goods, and employment. Income redistribution through the tax system could be considered with a view to addressing labour market inequalities by improving employment participation, raising low wages (especially where they lag significantly behind productivity developments). However, while there is room to increase the quality and efficiency of public spending to mitigate inequalities (as emphasized by EC (2012a), income redistribution policies have their limits, especially within the current fiscal environment in most EU countries.

(3) Another way to link supply and demand factors is to stimulate the creation and organization of the markets for ICT and ICT-enabled new products, for example by empowering ICT public and private users. For societies to obtain the advantages of the ICT

⁶³ EC (2012a), OECD (2011), UNESCO (2012).

⁶⁴ While the income effect of ICT is beyond the scope of this paper, mentioning wages is unavoidable in explaining certain employment effects.

⁶⁵ Lughini (1995), Pini (1997), Piacentini and Pini (2000), Fisher and Hostland (2002), Russel and Dufour (2007), Sharpe et al (2008), EC (2012a).

⁶⁶ Fisher and Hostland (2002), Russell and Dufour (2007), Sharpe et al (2008).

⁶⁷ Díaz-Chao et al (2009), Piacentini and Pini (2000), Vivarelli (1995), Vivarelli and Gatti (1995).

it is required that the great majority of the citizens have the necessary knowledge to participate in the digital economy. This emphasizes that education policy should be directed toward the use of digital technologies. The institutional context, as shown in the compensation theory literature, appears to be a very important factor in the analysis of the employment effects of ICT as it allows economic policies to encourage demand from public and private final consumers for ICT products and services, both at home and abroad.

(4) Several papers address the structural issue of destruction of working time and redistribution of available employment through lowering working time per employee. Thus, in an empirical study of four European countries, Spiezia and Vivarelli (2000) present evidence suggesting a pattern of labour destruction that has not turned into job destruction only because of a progressive reduction in per capita annual working hours. This study suggests that, if working time is used as a measure of employment, some European countries may have embarked on a pattern of long-term jobless growth. Moreover, the findings of another study, by Macias et al (2009), show that there has been an increase in the proportion of jobs with long hours of work towards the top of the wage distribution in most of the EU Member States over the period 2000-2005. Additionally, the authors claim there has been an increase in job quality in most European countries over the period of 1995-2005. While labour destruction, even when not translated into jobs destruction, may be considered counter-productive, the decrease in the total number of hours worked combined with increasing quantity and quality of employment and welfare is not necessarily a negative socio-economic outcome. Moreover, it suggests policy interventions through institutional adjustments in the form of a progressive reduction in per capita annual working time, as has happened in several European countries.

(5) Despite the growing number of ICT job vacancies, Europe has historically performed relatively weaker in its ability to build up an economic structure capable of facing competition with the US, Japan, India and China. This is mainly due to the fact that the non-ICT slower-growing sectors with reduced employment potential are more heavily represented in the sector composition of European industries.⁶⁸ A number of papers have collected evidence over the last three decades to show that European manufacturing employment has experienced periods of poor growth or job losses, and pointed to weak product innovation and prevailing labour-saving process innovation as the main causes.⁶⁹ The robust findings of numerous empirical studies (supporting both compensation and substitution frameworks) suggest that product and process innovations are important determinants of the employment outcomes of ICT.⁷⁰ The relevance of the distinction between product- and process-oriented innovation gives a new perspective to the comparison between Europe and the US and indicates the importance of the structural composition of economy, with product-oriented industries that generate and apply ICT-enabled innovations being the main engine of job creation in the medium and long term. As empirical findings suggest, most of the actual employment gains in Europe are due to the increase of the relative share of the service sector with respect to the industrial sector. This job-creating resource could be further exploited together with the job-creating potential of product-innovations led by ICT in the traditional fashion of the industrial policy tools, like taxes and subsidies, to favour one sector over another. It is important though to bear in

⁶⁸ Piacentini and Pini, 2000, Pianta, 2000, Pianta and Vaona (2007), Mastrostefano and Pianta (2007), Malerba (2002), Antonucci and Pianta (2002), Antonucci (2003) and others.

⁶⁹ Vivarelli et al (1996), Pianta (2000, 2001), Antonucci and Pianta (2002), Evangelista and Savona (2003), Mastrostefano and Pianta (2007).

⁷⁰ Van Reenen (1997), Garcia et al (2002), Harrison et al (2005) and others.

mind the actual policy objective of employment creation and not to slip into an industrial policy of “picking winners” or selecting “national champions” which have been shown to be inefficient by empirical studies.

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Abstract

This report surveys the literature on the employment impact of ICT. Two competing views, compensation and substitution theory, dominate the current economic debate. The first assumes that the labour-saving impact of technological progress is counterbalanced by various compensation mechanisms. The second asserts that technology causes job displacement, leading to polarization, de-skilling and possibly a jobless economy. Recent employment trends are often seen as indicative of mismatches between rapidly changing demand for skills and slow adjustment in the supply. Despite a wealth of theoretical models and empirical evidence, a consensus regarding the employment effect of ICT remains elusive. While there are many empirical studies on technological progress in general, few are based on specific ICT indicators. Our review devotes equal space to each mainstream economic theory on the complex connection between technology and employment, while giving greater emphasis to those studies which specifically look at ICT and that provide empirical support to sound theoretical grounds. This report recommends further empirical research on the specific employment impact of ICT.

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