For Official Use **DSTI/ICCP/IIS(2014)6/REV1**

Organisation de Coopération et de Développement Économiques
Organisation for Economic Co-operation and Development **10-Jun-2015**

English - Or. English

DIRECTORATE FOR SCIENCE, TECHNOLOGY AND INNOVATION
COMMITTEE ON DIGITAL ECONOMY POLICY

DSTI/ICCP/IIS(2014)6/REV1
For Official Use

Working Party on Measurement and Analysis of the Digital Economy

ICTS AND JOBS: COMPLEMENTS OR SUBSTITUTES?

THE EFFECTS OF ICT INVESTMENT ON LABOUR DEMAND IN 19 OECD COUNTRIES

OECD Headquarters, Paris, 24-26 June 2015

This document provides new estimates of the effects of ICT investments on total labour demand in 19 OECD countries over 1990-2012. By looking at the total economy, these estimates permit to measure both the positive and negative employment effects of ICTs. The document, which is part of a wider research agenda on "ICTs, jobs and skills" [DSTI/ICCP/IIS(2014)2], would contribute to session "4.1 New Markets and New Jobs in the Digital Economy" of the CDEP Ministerial Meeting in 2016.

This document was discussed at the WP-MADE in December 2014. The Working Party decided that, following a period for written comments that have now been incorporated; the document should be submitted to CDEP for declassification.

For further information please contact: Economic Analysis and Statistics Division (EAS), Vincenzo SPIEZIA, E-mail: vincenzo.spiezia@oecd.org

JT03378200

English - Or. English

ICTS AND JOBS: COMPLEMENTS OR SUBSTITUTES?

THE EFFECTS OF ICT INVESTMENT ON LABOUR DEMAND IN 19 OECD COUNTRIES

1. Introduction

1. Major technological innovations in economic history have always been accompanied by major transformations in the labour market. By increasing labour productivity, innovation enables producing a given amount of goods and services with less employment, thus leading to the possibility of *technological unemployment*. At the same time, innovation triggers a number of *compensation mechanisms* with potential positive effects on employment.

2. Information and communication technologies (ICTs) are no exception to this historical pattern. Information technologies can replace workers that perform routine tasks with computer-directed production processes (*automation*). Furthermore, communication technologies allow co-ordination of complex production activities across space and delocalisation of labour-intensive productions activities to low-wage countries (*offshoring*). At the same time, ICTs create new employment opportunities in the ICT sector and in the whole economy.

3. The overall effect of these different factors is predicted to be positive under the conditions postulated by economic theory in the long run. As economies may deviate from these conditions in the short run, the net employment effect of ICTs is likely to depend on institutions and policies.

4. This paper provides new estimates of the effects of ICT investments on total labour demand in 19 OECD countries over 1990-2012. By looking at the total economy, these estimates enable measurement of both the positive and negative employment effects of ICTs, which recent studies at the firm or industry level cannot account for. The paper is part of a wider research agenda on “ICTs, jobs and skills” [DSTI/ICCP/IIS(2014)2] that is intended to contribute to the evidence base for the CDEP Ministerial Meeting in 2016. Such a research agenda would also analyse further employment effects of ICTs via changes in industry specialisation, skills composition and global value chains.

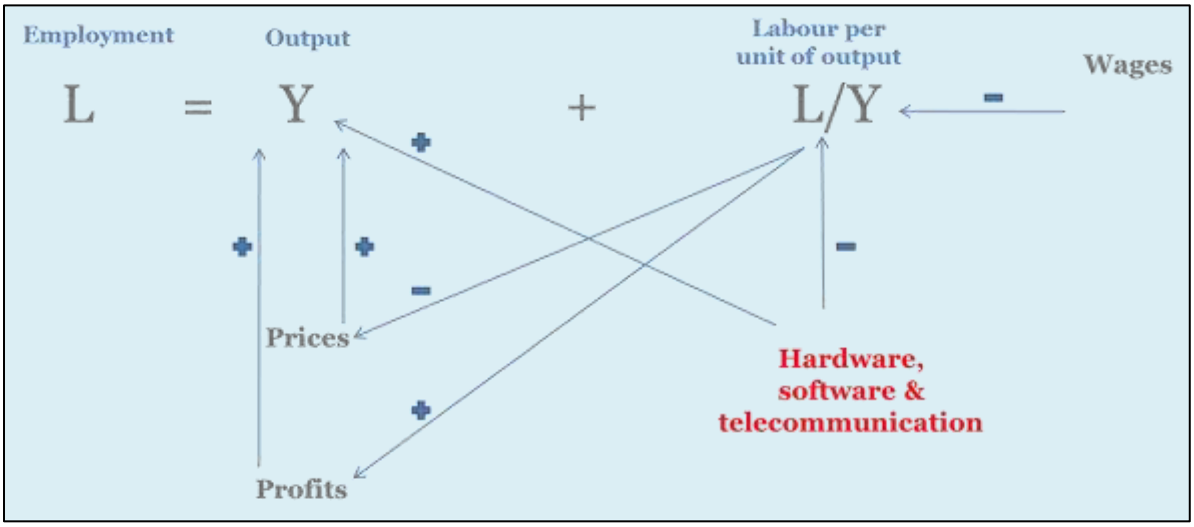
5. The paper is organised as follows. Section 2 summarises the main predictions of the economic theory on the effects of innovation on employment while Section 3 reviews recent empirical studies on the topic. Sections 4 and 5 introduce the model and the data for the analysis. The main findings are discussed in Section 6 while Section 7 concludes.

2. ICTs and employment: what does economic theory say?

6. The analysis of the effects of innovation on employment goes through the history of modern economics, e.g.: Say, Ricardo, Marx, Hicks, Marshall and Keynes, among others. The results of this analysis are known in the economic literature as “compensation theory”. At the core of compensation theory is the prediction that, while innovation may reduce labour demand and lead to unemployment, it also triggers a number of automatic mechanisms that are expected to compensate for the direct decrease in labour demand. The compensation theory also provides useful insights on the effects of ICTs on employment (OECD, 1994; Spiezia and Vivarelli, 2002).

7. Figure 1 provides an illustration of the opposing forces at play. Changes in employment (L) are the results of growth in output (Y) and the changes in the quantity of labour required to produce one unit of output (L/Y). As shown in the figure, ICTs have an impact both on labour requirements and on output.

Figure 1. Effects of ICTs on employment



8. To start with, it is useful to distinguish between process innovations and product innovations. A process innovation increases productivity and reduces unit costs whereas a product innovation results in the commercialisation of new goods and services. Interestingly, ICTs comprise both process innovations, e.g. computer-controlled machineries, automated inventory flows, and product innovations, e.g. smartphones, e-books, etc.

9. By increasing labour productivity, ICT process innovations permit to produce a given amount of goods and services with less employment, thus leading to the possibility of technological unemployment. This effect is stronger the larger the *labour-saving bias*[1] of the new technology, i.e.: the more ICTs reduce the demand of labour relative to that of capital, at constant input prices. The labour-saving bias may be different depending on the type of labour, e.g.: ICTs tend to be biased against low-skill workers and towards high-skill labour.

10. At the same time, ICT process innovations lead to lower unit costs of production. In a competitive market, this decrease is translated into lower prices, which stimulate higher demand for products. In turn, higher demand generates additional production and employment (compensation "via decrease in prices"). The strength of this effect depends positively on two factors: first, the degree of competition in the product markets; and, second, the price elasticity of final demand.

11. In less competitive product markets, the decrease in unit costs induced by ICTs is not fully translated into prices and generates extra-profits for the innovative firms. Part of these extra-profits is directly re-invested and increases production and employment in the capital good sector (compensation "via increase in machineries"). The other part provides additional income for share-holders (as dividends) and workers (through wage bargaining), who may spend it on higher consumption or save it. Higher consumption directly increases aggregate demand while savings are lent through the financial system to finance investment by firms and consumption by households. Through these different channels, the increase in income generated by ICTs raises aggregate demand, production and employment

1. According to Hick's classification of technological progress.

(compensation “via increase in income”). The strength of these effects would be larger the higher firms’ propensity to invest, the higher households’ propensity to consume and the higher the efficiency of the financial system to reallocate savings.

12. The direct effect of ICT process innovation on employment may be further compensated by a decrease in real wages, which leads to an increase in the labour-intensity of production and/or to a decrease in unit production costs (compensation “via decrease in wages”). The strength of the former effect depends on, first, the degree of substitutability between labour and the other production inputs and, second, the degree of wage flexibility in the labour market. The latter effect is the compensation “via decrease in prices” discussed above.

13. Finally, the commercialisation of new ICT goods and services increases consumption and production and raises the demand for labour (compensation “via new products”). This effect would be larger the lower the substitutability of new products with existing ones and the higher the labour intensity of the production of the new products. In respect to the latter factor, one may expect the labour intensity of ICT products to decrease faster than in other industries, as ICT producing industries are the most intensive users of ICT process innovations.

14. This brief recollection of the predictions of the compensation theory suggests three main considerations. First, the impact of ICTs on employment is the result of opposing forces, which operate through a variety of channels, agents and industries. Looking only at some of these forces is likely to provide a biased assessment of the employment impact of ICTs.

15. Second, the mechanisms that are expected to compensate for the direct, negative effect of ICT process innovations on employment depend on several conditions that may not apply in reality, e.g.: additional income generated by ICT process innovations may not be fully spent or invested, or that may take time to become effective, e.g.: lower unit costs are not immediately translated into lower prices.

16. Finally, the compensation for the decrease in labour demand that may result from ICTs occurs through the mobility of resources – financial capital, knowledge assets and labour– across firms and sectors. By its very nature, this process of structural change takes time and may be hampered by institutional barriers and market imperfections. More fundamentally, entrepreneurial skills, intangible assets and workers’ skills tend to be industry specific and may not be fit to the business environment, the work organisation and the tasks composition of the activities where they would have to move. This is likely to be the case especially for new markets that did not exist before, like those created by new ICT goods and services.

3. Innovation and employment: findings from recent studies

17. Several empirical studies have analysed the relationship between innovation and employment. While only few of them focus on ICTs, their findings shed light on the effectiveness of the compensation mechanisms discussed in the previous section.

18. In the 1980s and 1990s, macroeconomic analysis dominated the research on the employment effects of innovation (e.g.: Layard and Nickell, 1994; Freeman and Soete, 1994; Machin and Van Reenen, 1998) whereas more recent analyses on this topic have been carried at the sectoral or firm level. Given the scope of the paper, this section reviews the latest studies only (see Sabadash, 2013 for a review of earlier studies).

19. In general, sectoral studies show that structural change is the driving force behind employment growth, with opportunities for both innovation and for jobs being sector-specific. Industry-level evidence for the 1990’s and early 2000’s in Europe suggests that the decrease in manufacturing employment was

due to a combination of weak final demand, increasing wage, and the prevalence of labour-saving process innovations over product innovations (Pianta and Bogliacino, 2010; Bogliacino and Vivarelli, 2011). Job losses occurred mostly in large firms, among low-skilled workers, in ICT and capital-intensive industries and in the financial sector. Job creation was concentrated in industries with high demand growth and those where product innovation dominated process innovation, as well as in open economies specialised in innovative and fast growing activities.

20. While the positive employment effects of product innovation are confirmed by firm-level studies, the effects of process innovations range from negative to positive according to the methodology and the dataset used in each study.

21. A series of studies on European CIS (Community Innovation Survey) data based on a common micro-founded model (Peters, 2004; Harrison *et al.*, 2008) find out that employment losses are largely concentrated in non-innovating firms while employment growth is mainly driven by the introduction of new products. Process innovation was found to have negative employment effects only in German manufacturing industry.

22. Hall, Lotti, and Mairesse (2008) run a similar model on a panel of Italian manufacturing firms over the period 1995–2003 and find positive employment effects for product innovation but no significant effect for process innovation.

23. Lachenmaier and Rottmann (2011) estimate a dynamic employment equation on a dataset of German manufacturing firms over the period 1982–2002. They find positive employment effects for different innovation measures, including process innovation.

24. Coad and Rao (2011) find out a positive correlation between employment and a composite innovativeness index (including both R&D and patents) in US high-tech manufacturing firms over the period 1963–2002.

25. Bogliacino, Piva, and Vivarelli (2011) analyse a longitudinal database covering 677 European manufacturing and service firms over the period 1990–2008 and find a positive impact of R&D expenditures on employment in services and high-tech manufacturing but not in traditional manufacturing.

26. Finally, Evangelisti and Vezzani (2011) find out that all types of innovation – including organisational innovation – affect employment indirectly by improving performances, leading to higher sales and more jobs. However, the classical distinction between product and process innovation is not able to capture these differentiated effects. Innovation strategies characterized by a combination of product, process and organizational innovations show the strongest positive impact on employment, whereas the negative direct effects of process innovations are found only in the manufacturing firms when process innovations are combined with organizational changes.

27. Different measures of innovation and ICTs are likely to explain to a large extent the different findings of these studies. In a study on Germany, Severgnini (2009) provides an interesting comparison among three different measures of ICTs: 1) a time trend, 2) the ratio of ICT investment to output; and 3) the contribution of ICTs to total factor productivity. These measures give opposite results. When ICTs are measured by a time trend, their employment effects tend to be negative in the short run and positive in the long run. However, long-run effects become statistically not significant when labour and product market regulations are controlled for. The second measure – the ratio of ICT investment to output - has mixed effects on employment while the third measure – the contribution of ICTs to multi factor productivity - has negative effects in both the short and the long run.

28. While firm-level analyses permit a richer characterisation of innovation strategies and avoid the confounding effects from averaging different behaviours at the sectoral or macro level, they miss out the employment effects that ICTs may have in other firms, industries or countries.

29. First, firm-level databases are, in general, not representative of all firms and tend to be biased towards large manufacturing ones.

30. Second, micro-level studies do not distinguish whether employment growth in innovative firms results in net job creation - through “market expansion” - or it occurs at the expense of their rivals – through “business stealing”. For instance, Greenan and Guellec (2000) show that the positive employment effects of process innovation found in French firms disappear at the industry level.

31. Finally, when the business stealing effect is accounted for, firm-level analysis does not measure to what extent the same innovation that destroys jobs in one industry may result in job creation in a different industry via the compensation mechanisms discussed in section 2.

32. Recent estimates of ICT employment multiplier based on input-output analysis suggest that these indirect effects are sizable. Such multipliers measure the overall increase in employment generated by 1 additional job in the ICT industry.

33. Katz (2012) reviews the broadband employment multiplier estimated by different studies: their values vary between 1.92 in Germany and 3.6 in the United States. Mandel and Scherer (2012) estimate that each new job in the mobile application industry generated another 0.5 jobs in the rest of the economy.

34. In their study of the employment impact of Facebook app development in the US, Hann *et al.* (2011) estimate multipliers of 2.4 for the broadband industry, 2.5 for the communication sector and 3.4 for the whole economy.

35. Moretti (2012) estimates that the high-tech job multiplier is as high as 5: for each job created in the software, technology and life-sciences industries in the United States over 2000-10, five new jobs are indirectly created in the local economy, 2 in high-skill occupations (e.g.: doctors and lawyers) and 3 in low-skill occupations (e.g.: waiters, barbers and store clerks).

36. Mazzolari and Ragusa (2013) find evidence of a strong positive relationship in the United States between the change in a city top-wage-bill share and the growth in local employment in jobs that substitute for home production. Consumption spillovers may account for one third of the growth of employment in home production substitutes experienced in the 1990s by non-college workers in the United States.

4. Modelling the effects of ICT on employment

37. This paper analyses the effects of ICTs on employment within the standard labour demand theory. This framework has the advantage to model the employment effects of ICTs as a result of firms’ decisions and market mechanisms rather than as a technology-driven outcome.

38. Fast technological progress in ICTs has led to a rapid decrease in the price of ICT equipment and software and to large investments in ICTs. Such investment have resulted into changes in the production mix of labour, ICT capital and other types of capital, on the one hand, and into a decrease in production costs and an increase in final demand, via lower prices and/or higher income, on the other.

39. The net impact of technological progress embodied in ICT capital on labour demand depends, therefore, on: *i)* the extent to which ICT capital substitutes for labour (*partial elasticity of substitution*); and *ii)* the extent to which lower unit costs generate higher demand and production via a decrease in prices (*price elasticity*) and/or an increase in income (*income elasticity*).

40. For the total economy, economic theory predicts that both the price elasticity and the income elasticity of final demand are equal to one[2]. Indeed, any decrease in the output price raises real income, thus leading to a proportional increase in real consumption and/or savings. Similarly, any increase in extra-profits raise nominal income, consumption and/or savings by the same proportion. By an accounting identity, savings equals (domestic plus foreign) investments. Therefore, any decrease in the output price and any increase in income would translate into an equal increase in final demand (consumption plus investments).

41. It follows that ICT investments increases or reduce labour demand depending on whether the elasticity of substitution between labour and ICT capital is smaller or bigger than one, i.e.: on whether labour and ICT capital are complements or substitutes. The main aim of this study is, therefore, to estimate the value of the partial elasticity of substitution between labour and ICT capital. Annex 1 provides a formal description of the model and its econometric specification.

42. This approach accounts for the employment effects of technological progress embodied in ICT capital goods but it does not consider disembodied technical change, i.e.: increase in productivity that does not occur through new investment. The latter has effects both on the substitution between labour and ICT capital, on the one hand, and on the decrease in output price, on the other.

43. First, as discussed in section 2, disembodied technical change reduces the demand for labour per unit of output if it is labour-saving. Therefore, estimates based on embodied technical progress only may underrate the negative impact of ICTs on employment. Second, disembodied technical progress raises multifactor productivity (MFP) thus reducing unit cost and output prices. Not accounting for disembodied technical change may, therefore, underestimate the positive effects of ICTs on final demand and employment.

44. While it is hard to quantify disembodied technical progress due to ICTs, two considerations suggest that the above measurement errors may not be large. First, there is growing evidence that: *i)* a significant part of MFP is associated with investment in intangible assets (OECD, 2013) and *ii)* for ICT capital to raise productivity, it requires complementary investments in intangible assets (Corrado *et al.*, 2014). Therefore, ICT investments are strongly correlated to intangible assets and are likely to capture a significant proportion of disembodied technical progress due to ICTs.

45. Second, firms' expectations about the future value of ICT capital services would also reflect productivity increases due to disembodied technical progress stemming from ICTs. As discussed in the following section, such expectations are reflected in ICT capital user costs and in the investment decisions by firms. Therefore, to the extent firms anticipated the productivity effects of disembodied technical progress, these effects would be also be captured by the estimates provided in this paper.

2 These predictions are confirmed in our dataset by hypothesis testing based on a cluster-robust GLS estimation (see Annex 1).

5. The dataset

46. The data for the analysis are drawn from the OECD Productivity Database (PDB), http://www.oecd.org/std/productivity-stats/. The PDB combines a consistent set of data on GDP, labour input, capital services, hourly wage and capital user costs for 19 countries over 1985-2012. The default source for the dataset is generally the OECD's Annual National Accounts, although other sources have been used when national accounts data were not available.

47. Labour input is defined as total hours worked of all persons engaged in production.

48. Capital inputs are measured as capital services: for any given type of asset, there is a flow of productive services from the cumulative stock of past investments. Estimates of capital services in the OECD Productivity Databases are based on the perpetual inventory method (PIM). The PIM calculations are carried out by the OECD, using an assumption of common service lives for given assets for all countries, and by correcting for differences in the national deflators used for hardware, communications equipment and software assets (Schreyer, 2001, Schreyer *et al.*, 2003). The "harmonised" deflators assume that the ratios between ICT and non-ICT asset prices evolve in a similar manner across countries, using the United States as the benchmark.

49. Capital service flows in the PDB relate to non-residential fixed capital only and have been computed at the level of the total economy for 19 OECD countries. They can be broken down by seven types of assets: Hardware and office machinery; Communication equipment; Other machinery and equipment; Transport equipment; Non-residential construction; Software; and Other products.

50. The price of ICT capital services is the most important information for the purpose of this paper. In general, the price of capital services is measured as their rental price. If there were complete markets for capital services, rental prices could be directly observed. This is, however, not the case for many capital goods that are owned and for which rental prices have to be imputed. The implicit rent that capital good owners 'pay' themselves gives is defined as user costs of capital.

51. Typically, the user cost for an older piece of capital is lower than the user cost for a new capital good, reflecting the differences in productive efficiency of the two items. Therefore, the price for capital services will vary as a function of the age of the capital good.

52. The derivation of user costs is fairly complex and requires a number of hypotheses (see Schreyer, 2003 for an exhaustive discussion). Such hypotheses are fully consistent to those that underline the theoretical model presented in the previous section.

53. It is worth noticing that, unlike in other databases, e.g.: EUKLEMS, the user cost of capital is not estimated by imposing the equality between capital remuneration and gross operating surplus (value added minus total wages) but it is based on firms' expectations about future capital productivity. Furthermore, this approach does not require perfect competition in the product market nor constant returns to scale in production (Schreyer, 2010).

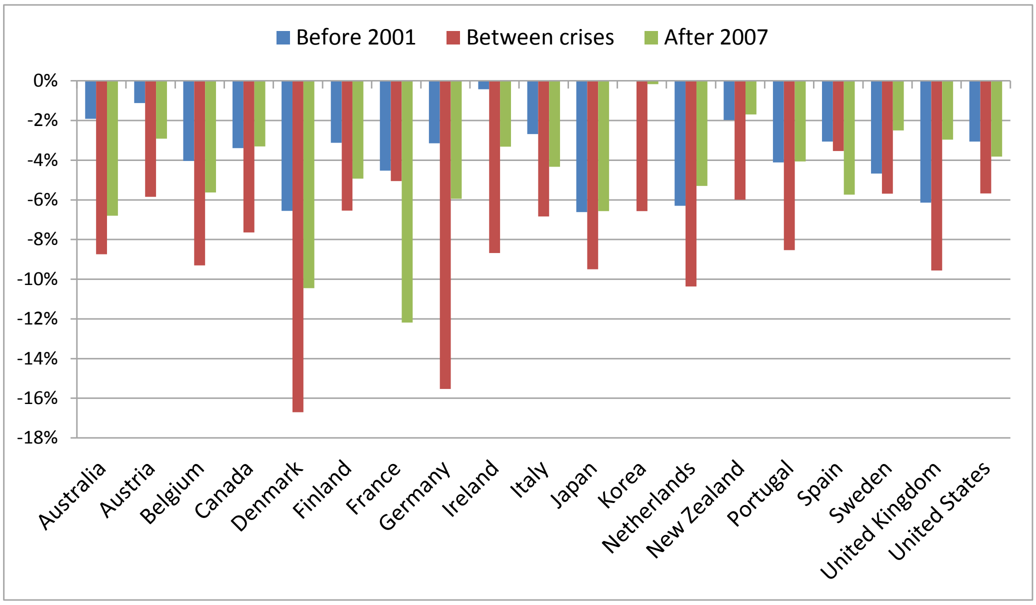
54. Keeping aside more technical issues, two theoretical assumptions are crucial to the estimation of user costs. First, in a fully functioning asset market, the purchase price of an asset will equal the discounted flow of the value of services that the asset is expected to generate in the future (Jorgenson, 1963). Second, a rational, cost-minimising producer will choose a vintage composition such that the relative productivity of different vintages is just equal to the relative user costs of the two vintages (Hulten, 1990).

55. It follows from these two assumptions that technical progress embodied in new, more efficient ICT capital would be "measured" by a decrease in their user cost. This feature provides the rationale for assessing the employment effects of ICTs by looking at the impact of ICT user costs on labour demand.

56. Changes in ICT user costs do not simply reflect improvements in technology but they also depend on firms' expectations about the future value of ICT capital services. Therefore, for a given ICT technological trend, country differences in the factors that affect these expectations, e.g.: competition, regulation, cost of borrowing, consumer preferences, market size, etc. may affect the expected value of ICT capital services and the evolution of user costs.

Figure 2. Change in the user cost of ICT capital, 1990-2012

Average yearly rate (%)



Note: See Annex 2 for country-specific periods.

Source: Own calculations based on the OECD Productivity Database, 4 September 2014, http://www.oecd.org/std/productivity-stats/.

57. Figure 2 shows the dynamics of the user cost of ICT capital over 1990-2012 for the three periods early 1990s-2001, 2001-2007 and 2008-2012. These periods correspond to three phases of the business cycle: before the dot.com bubble, after the subprime crisis and between the two crises. As the business cycle was not fully synchronised among countries, these periods are specific to each country, as indicated in Annex 2.

58. Figure 2 shows two main trends. First, in all countries the decrease in ICT user costs has been faster in the second period (2001-2007) than in the first one (before 2001). The 2001-2007 decrease was the largest in Denmark (about 17% a year) and Germany (just below 16%). Second, in most countries, the decrease in ICT user costs has continued after the crisis but at a significantly slower rate. This slowdown is likely to reflect lower firms' expectations about future growth due to the crisis. France and Spain are the only exceptions to this trend, as ICT user costs decreased at a faster rate than before.

6. Results

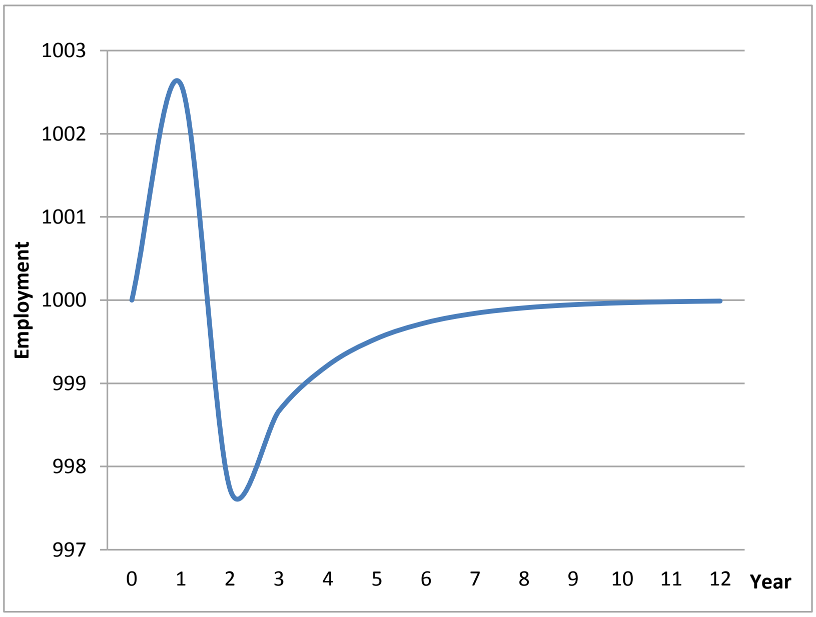
59. Detailed regression outputs are reported in Annex 1. The estimates provide two main results:

60. In the long run, the partial elasticity of substitution between labour and ICT capital is equal to one in all countries. Therefore, a permanent decrease in the user cost of ICT capital reduces labour demand per unit of output but it increases output by the same proportion. In other words, the substitution effect and the scale effect compensate each other completely. As a result, based on these estimates, investments in ICTs do not have any effect on labour demand in the long-run.

61. In the short run, however, firms cannot change production inputs immediately because of staggered contracts, regulations and other adjustment costs. In addition, ICT investments are likely to trigger a process of reallocation of production inputs across industries and this process takes time. As a consequence, a permanent decrease in the user cost of ICT capital does have an impact on labour demand in the short run. The adjustment path of employment can be described as follows.

Figure 3. Change in employment following a permanent 5%-decrease in the user cost of ICT capital

Initial labour cost share is equal to 0.775



Source: Own estimates on the regression output – see Annex 1 for details.

62. In the first period, production techniques are fixed because it takes time for firms to change inputs. A decrease in the user costs of ICT capital leads to lower costs and prices and higher demand. As a result, firms hire more and employment increases. In the next period, firms can change their production technique. At a lower user of cost of ICT capital, they invest more in ICTs and reduce labour. As the hiring started in the first period is still producing its effects due to staggered contracts and adjustment costs, firms reduce employment below its long run level. In the following periods, therefore, firms progressively increase employment as to bring it back to equilibrium.

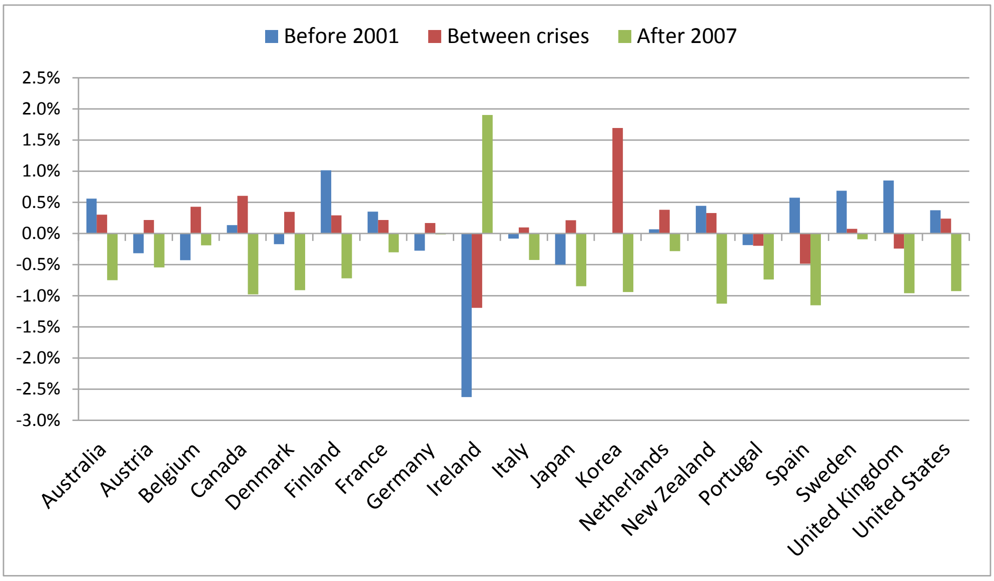
63. The adjustment path following a permanent decrease in ICT user costs is illustrated in Figure 3. The changes in employment are larger the larger the decrease in ICT user costs and the smaller the labour share in total costs. The return of employment to its long run level is also slower the smaller the labour share. For the values of the labour share in OECD countries – between 0.65 and 0.88 - the negative employment effects disappear after about 10 years.

64. This dynamic is compounded by the fact that the permanent decrease in the user cost of ICT capital is not a "one-off" but it has been a continuous trend over more than two decades. Therefore, the employment effects have accumulated over time and become more persistent. In general, the employment effect of ICT remains positive for as long as the decrease in ICT user cost occurs at an increasing rate. When the decrease in ICT user cost slows down, the negative short-run effects of past capital accumulation prevail and result into a decrease in labour demand.

65. Figure 4 shows the estimated change in employment driven by the accumulation of ICT capital over 1990-2012 for the three periods 1990-2001, 2001-2007 and 2008-2012, as discussed in Section 5.

Figure 4. Employment growth due to growth in ICT capital

Average yearly rates



Source: Own estimates based on the regression output – see Annex 1 for details.

66. In 10 out of 19 countries, the estimates suggest that ICT investments have raised employment in both the period before 2001 and the subsequent period 2001-2007. With the exception of Canada and the Netherlands, the employment effects of ICT investment were smaller in the second period, due to the accumulation of short-run negative effects over time and the slowdown in the decrease in the user cost of ICT capital. In Canada and the Netherlands, ICT user costs decreased later than in other countries, which explains why the positive effects are bigger in the second period.

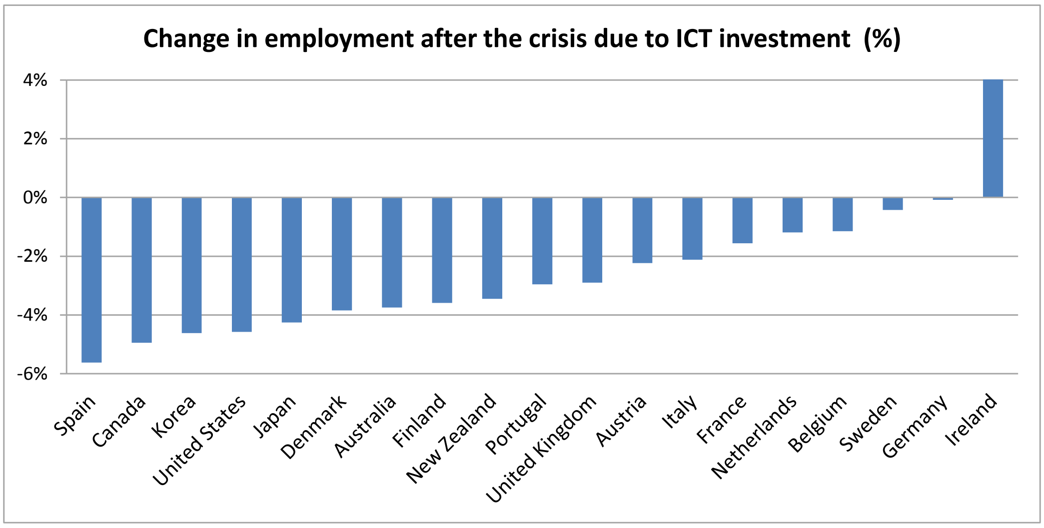
67. The negative employment effects before 2001 in the remaining 7 countries have been due to a less rapid decrease in ICT user costs.

68. In the period after 2007, ICT investments have resulted in a decrease in labour demand in almost all countries (Figure 5). The decrease is mainly due to a slowdown in the decrease in the user cost of ICT capital together with the negative effects of sustained ICT investment over the previous period.

69. Ireland and Portugal are the only two exceptions to these common trends. In Ireland both the crisis and the recovery started earlier than in the other countries while in Portugal ICT investments seem to have resulted in a decrease in employment in all three periods.

Figure 5. Change in employment after the crisis due to ICT investments

As a percentage of employment in the year before the crisis



Source: Own estimates on the regression output – see Annex 1 for details.

70. The above estimates suggest that, in most OECD countries, the secular increase in ICT productivity has had a negative impact on employment since 2007 at least. While these effects are estimated to fade away eventually, their size and persistence seem high enough to justify appropriate policy measures. As the post-2007 decrease in labour demand appears to be related to a slowdown in ICT investments, policies to foster such investments would be beneficial to employment. Also, the cost of temporary job losses due to the accumulation of past ICT investments could be relieved through labour market activation policies and temporary income support.

7. Conclusions

71. This study provides new estimates of the employment impact of ICT investments in 19 OECD countries over the period 1990-2012. Its approach has been to measure ICT technical progress as the decline in the user cost of ICT capital and to estimate the effects of such decline on the demand for labour.

72. The findings suggest that ICT investments have no effects on labour demand in the long run. A permanent decrease in the user cost of ICT capital reduces labour demand per unit of output but it increases output by the same proportion. In other words, the substitution effect and the scale effect compensate each other completely.

73. In the short run, however, due to sluggish adjustments in production inputs, a permanent decrease in ICT user cost results into a temporary decrease in labour demand. Our estimates suggest that the negative effect of a "one-off" permanent decrease in ICT user costs tend to disappear in about 10 years in OECD countries.

74. These effects are more persistent because the decrease in the user cost of ICT capital has been a continuous trend over more than two decades and the partial elasticity of substitution between labour and ICT capital has been changing over time.

75. In 10 out of 19 countries, ICT investments have raised employment in both the period before 2001 and the subsequent period 2001-2007. In the period after 2007, ICT investments have resulted into a decrease in employment in all countries except Ireland, where the recovery has started earlier. Portugal is the only country where ICT investments have resulted into a decrease in employment in all three periods considered.

76. While the negative employment effects of ICTs are estimated to fade away eventually, their size and persistence seem high enough to justify appropriate policy measures, such as incentives to ICT investments, labour market activation policies and temporary income support.

77. This study has looked at the impact of ICT investments on the level of employment but not on its composition. As discussed in DSTI/ICCP/IIS(2014)8, there is evidence that ICTs tend to replace low-skill, non-manual tasks while increasing but the demand for high-skill, non-routine ones. Depending on data availability, the present framework could be extended to estimate labour demand for different types of skills or educational attainments.

ANNEX 1

THE EFFECTS OF ICT INVESTMENTS ON LABOUR DEMAND – THEORETICAL MODEL AND ECONOMETRIC SPECIFICATION

Consider a firm using three factors of production: labour (H), ICT capital (IT) and non-ICT capital (K). Holding output and other input prices constant, cost minimisation implies that (Hamermesh, 1986):

1. $\frac{\partial lnH}{\partial \ln w_{IT}} = c_{IT} * \sigma_{H,IT}$

where w_{IT} is the user cost of ICT capital, c_{IT} the cost share of ICT capital and $\sigma_{H,IT}$ the partial elasticity of substitution between labour and ICT capital. The latter measures the percentage change in the labour-ICT capital ratio from a change in the wage-ICT user cost ratio, holding output and other input prices constant.

Equation 1 states that, following a 1%-decrease in the user cost of ICT, firms reduce labour per unit of output by $c_{IT} * \sigma_{H,IT}$ per cent. This reflects the *substitution effect* along an isoquant, i.e.: at a constant output.

When the ICT user cost decreases, unit costs of production (*c*) decrease as well by:

2. $\frac{\partial lnc}{\partial lnw_{IT}} = c_{IT}$

Depending on the degree of competition in the product market, part of the decrease in unit costs would be translated into lower product prices, part into higher monopolistic rents.

Under perfect competition, the decrease in unit cost is fully translated into a decrease in price ($dlnp^C$):

3. $\frac{\partial lnp^C}{\partial lnw_{IT}} = \frac{\partial lnc}{\partial lnw_{IT}} = c_{IT}$

Under imperfect competition, the decrease in price ($dlnp^M$) following a decrease in ICT user costs is:

4. $\frac{\partial lnp^M}{\partial lnw_{IT}} = (1 - s_M) * \frac{\partial lnc}{\partial lnw_{IT}} = (1 - s_M) * c_{IT}$

where s_M is the share of monopolistic rents in total value added. The increase in monopolistic rents per unit of output from a decrease in ICT user costs is therefore:

5. $\frac{\partial lnc}{\partial lnw_{IT}} - \frac{\partial lnp^M}{\partial lnw_{IT}} = -s_M * c_{IT}$

Lower prices and higher income (i.e.: monopolistic rents) would raise final demand and output (*scale effect*). The increase in output would then depend on the cost share of ICT capital (c_{IT}) as well as the elasticity of final demand to prices (ε) and to income (η).

The total effect on employment, i.e.: *substitution effect* plus *scale effect*, is therefore:

6. $\frac{\partial \ln H}{\partial \ln w_{IT}} = c_{IT} * \sigma_{H,IT} - \varepsilon * (1 - s_M) * c_{IT} + \eta * (-s_M * c_{IT})$

For the total economy, the economic theory predicts that both the price elasticity (ε) and the income elasticity (η) of final demand are equal to one. Indeed, any decrease in the output price raises real income, thus leading to a proportional increase in real consumption and/or savings. Similarly, any increase in extra-profits raise nominal income, consumption and/or savings by the same proportion. By accounting identity, savings equals (domestic plus foreign) investments. Therefore, any decrease in the output price and any increase in income would translate into an equal increase in final demand (consumption plus investments).

These predictions are confirmed in our dataset by the estimates from the following regression:

7. $\Delta lnGDP_{i,t} = \gamma * \Delta lnGDP_{i,t-1} - \varepsilon * \Delta lnc_{i,t} + \eta * \Delta ln\left(\frac{p_{i,t}}{c_{i,t}}\right) + e_{i,t}$

which are reported in table 1 below.

Table 1. Fixed-effect estimates of the price and income elasticity of final demand

Robust standard errors

	Estimates	t	R^2	
γ	0.273	4.39	within:	0.81
ε	0.958	5.75	between	0.78
η	0.904	4.65	overall	0.81
Year dummies	Yes			
			Number of obs	332
			Number of groups	19
			rho	0.215

The hypotheses that both the price elasticity (ε) and the income elasticity (η) are equal to 1 are not rejected at the conventional statistical levels.

Therefore, equation 6 simplifies to:

8. $\frac{\partial lnH}{\partial \ln w_{IT}} = c_{IT} * (\sigma_{H,IT} - 1).$

ICT investments increase or decrease labour demand depending on whether the elasticity of substitution between labour and ICT capital is smaller or bigger than 1, i.e.: on whether labour and ICT capital are complements ("friends") or substitutes ("enemies").

The choice of the production function plays a main role in the estimation of this parameter. Popular production functions, e.g.: the Cobb-Douglas or the CES, impose restrictions on the elasticity of substitution. In order to avoid these restrictions, the present analysis uses a translog production function (Christensen *et al.*, 1973), which allows for the elasticity of substitution to vary over time and across countries and contains the Cobb-Douglas and the CES function as special cases.

The cost (C) function associated to a translog production function can be written as:

9. $lnC = lnY + a_0 + \sum_i a_i * lnw_i + 0.5 * \sum_{i,j} b_{i,j} * lnw_i * lnw_j$

where *i,j* = H, IT and K, Y denotes output, $\sum_i a_i = 1, b_{i,j} = b_{j,i}$ and $\sum_j b_{i,j} = 0$, for all *j*.

By Shepard's lemma:

10. $\frac{\partial lnC}{\partial lnw_H} = \frac{H * w_H}{C} = c_H$

where both sides of the labour demand equation have been multiplied by w_H/C and labour remuneration has been assumed equal to its marginal products.

By differentiating equation 9, we can rewrite c_H as:

11. $c_H = a_H + \sum_j b_{H,j} * lnw_j$

The partial elasticity of substitution between labour and ICT capital is therefore:

12. $\sigma_{H,IT} = 1 + \frac{\frac{\partial c_H}{\partial lnw_{IT}}}{c_H * c_{IT}}$

Equation 11 is linear in lnw_i and can be estimated through standard econometric methods. The estimates from 11 can then be plugged into equation 12 to obtain an estimate of the partial elasticity of substitution between labour and ICT capital. As all variables on the right-hand side of 12 vary across countries and over time (both subscripts are omitted for sake of clarity), it follows that the estimated elasticity of substitution will differ across countries and over time.

Equation 11 has been estimated in differences in order to avoid issues related to unit roots and time-constant country-specific omitted variables. Three estimation techniques have been employed: random effects, IV - using lagged values of independent variables as instruments - and GMM. IV and GMM reject the hypotheses that input costs are endogenous and generate the same estimates as the random effects. The estimated regression is therefore:

13. $\Delta c_{H,t} = \alpha * \Delta c_{H,t-1} + \sum_j \sum_{s=0}^{2} b_{H,j,t-s} * lnw_{j,t-s} + \sum_t d_t + e_t,$ $j = H, IT$ and K

where d_t are year dummies. The estimated coefficients are reported in table 2.

Table 2. Random-effect estimates of changes the cost share of labour

$\Delta c_{H,t}$	Estimates	Z	R2	
			within:	0.89
$\Delta c_{H,t-1}$	0.5862	10.8	between:	0.92
			overall:	0.89
$b_{H,H,t}$	0.0625	4.06		
$b_{H,H,t-1}$	-0.1433	-5.96		
$b_{H,H,t-2}$	0.0738	5.07	**Number of obs**	332
			Number of groups	19
$b_{H,IT,t}$	-0.0492	-8.91		
$b_{H,IT,t-1}$	0.0746	7.94		
$b_{H,IT,t-2}$	-0.0284	-4.47		
$b_{H,K,t}$	-0.1176	-26.4		
$b_{H,K,t-1}$	0.1812	16.9		
$b_{H,K,t-2}$	-0.0654	-7.57		

The hypothesis that $\sum_{s=0}^{2} b_{H,j,t-s} = 0$ is not rejected for any j. This implies that in the long run, i.e.: $\Delta c_{H,t}=\Delta c_{H,t-1}$, a permanent change in the input costs has no effect on the labour share.

In particular, the long-run partial elasticity of substitution between labour and ICT capital (equation 12) equals 1 and a decrease in the ICT user cost has no effect on labour demand (equation 8).

In the short run, however, the partial elasticity of substitution between labour and ICT capital may differ from one because of the lagged effects of both $\Delta c_{H,t}$ and $dlnw_{IT}$. For employment to converge to its long run level, it must hold that $\Delta c_{H,t-1}* b_{H,IT,t-1} + b_{H,IT,t-1} <0$, an hypothesis that is not rejected. As a result, a permanent decrease in ICT user costs lead to temporary changes in labour demand, as illustrated in Figure 3.

These estimates can be further improved by estimating a 3-equation system comprising equation 7, equation 11 and the equivalent of equation 11 for one of the other production inputs (either ICT or non-ICT capital).

ANNEX 2

Table 3. Country-specific phases of the business cycle

Country	Before 2001	Between crises	After 2007
Australia	1990-2000	2001-2006	2007-2011
Austria	1997-2000	2001-2008	2009-2012
Belgium	1997-2001	2002-2006	2007-2012
Canada	1992-2001	2002-2007	2008-2012
Denmark	1999-2001	2002-2008	2009-2011
Finland	1992-2000	2001-2007	2008-2012
France	1992-2001	2002-1007	2008-2012
Germany	1992-2002	2003-2007	2008-2012
Ireland	1999-2003	2004-2010	2010-2012
Italy	1992-2001	2002-2007	2008-2012
Japan	1997-2000	2001-2007	2008-2012
Korea	*n.a.*	2004-2007	2008-2012
Netherlands	1997-2001	2002-2007	2008-2012
New Zealand	1992-2001	2002-2007	2008-2012
Portugal	1997-2001	2002-2007	2008-2012
Spain	1997-2001	2002-2007	2008-2012
Sweden	1995-2000	2001-2007	2008-2012
United Kingdom	1996-2001	2002-2007	2008-2011
United States	1992-2001	2002-2007	2008-2012

REFERENCES

Bogliacino, F., and M. Vivarelli (2011), “The Job Creation Effect of R&D Expenditures” *IZA Discussion Papers*, 4728. Bonn, Germany: IZA.

Bogliacino, F., M. Piva, and M. Vivarelli. 2011. “R&D and Employment: Some Evidence from European Microdata.” IZA Discussion Papers, 5908. Bonn, Germany: IZA

Bogliacino, M. and M. Pianta (2010), “Innovation and employment: a reinvestigation using revised Pavitt classes”, *Research Policy 39 (6).*

Christensen, L., D. Jorgenson and L. Lau (1973), "Transcendental logarithmic production frontiers", *Review of Economics and Statistics*, 55:28-45.

Coad, A., and R. Rao. 2011. “The Firm-level Employment Effects of Innovations in High-Tech U.S. Manufacturing Industries.” *Journal of Evolutionary Economics,* 21: 255–83.

Evangelista, Rinaldo and and Antonio Vezzani (2011), “The impact of technological and organizational innovations on employment in European firms”, *Industrial and Corporate Change*, Volume 21, Number 4, pp. 871–899.

Corrado, Carol, J. Haskel and C. Jona-Lasinio (2014), “ICT, R&D and Non-R&D Intangible Capital: Complementary Relations and Industry Productivity Growth”, 3rd World KLEMS Conference, 19-20 May 2014, Tokyo http://www.researchgate.net/publication/266209151.

Freeman, C., and L. Soete. 1994. *Work for All or Mass Unemployment? Computerised Technical Change into the Twenty-first Century*. London-New York: Pinter.

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

Hall, B.H., F. Lotti, and J. Mairesse (2008), “Employment, Innovation, and Productivity: Evidence from Italian Microdata.” Industrial and Corporate Change, 17: 813–39.

Hamermesh, Daniel S. (1986), “The demand for labour in the long run”, in O. Ashenfelter and R. Layard (eds.), *Handbook of Labor Economics, Volume 1*, @Elsevier Science Publishers BV.

Hann, Il-Horn, Siva Viswanathan, and Byungwan Koh (2011) “The Facebook App Economy” Robert H. Smith School of Business, Center for Digital Innovation, Technology and Strategy, University of Maryland.

Harrison, R., J. Jaumandreu, J. Mairesse, and B. Peters. (2008), “Does Innovation Stimulate Employment? A Firm-level Analysis Using Comparable Microdata from Four European Countries.” *NBER Working Papers, 14216*. Cambridge MA: NBER.

Hulten, Charles R. (1990); “The Measurement of Capital”; in Berndt, Ernst R. and Jack Triplett (eds.); *Fifty Years of Economic Measurement*, University of Chicago Press.

Jorgenson, Dale W. (1963); “Capital Theory and Investment Behaviour”; *American Economic Review, Vol. 53, pp. 247-259.*

Katz, Raoul (2012), “The Impact of Broadband on the Economy: Research to Date and Policy Issues”, *ITU Broadband Series*, ITU, Geneva.

Lachenmaier, S., and H. Rottmann. 2011. "Effects of Innovation on Employment: A Dynamic Panel Analysis. *International Journal of Industrial Organization*, 29, 210–20.

Layard, R., S. Nickell, S., and R. Jackman (1994), *The Unemployment Crisis*. Oxford: Oxford University Press.

Machin, S., and J. Van Reenen. 1998. "Technology and Changes in Skill Structure: Evidence from Seven OECD Countries." *Quarterly Journal of Economics*, 113: 1215–44.

Mandel, Michael and Judith Scherer (2012) "The Geography of the App Economy", *South Mountain Economics*.

Mazzolari, Francesca and Giuseppe Ragusa (2013). "Spillovers from High-Skill Consumption to Low-Skill Labor Markets", *Review of Economics and Statistics*, 95(1), 74-86.

Moretti, Enrico (2012) *The New Geography of Jobs*, Mariner Books, Houghton Mifflin Harcourt, Boston, New York.

OECD (2013), *New Sources of Growth: Knowledge-based Capital – Key Analyses and Policy Conclusions – Synthesis Report*. Paris, OECD.

OECD (1994), *The OECD Jobs Study: Facts, Analysis and Strategy*. Paris, OECD.

Peters, B. (2004), "Employment Effects of Different Innovation Activities: Microeconometric Evidence." ZEW Discussion Papers, 0473. Bonn, Germany: ZEW.

Sabadash, Anna (2013), "ICT-induced Technological Progress and Employment: a Happy Marriage or a Dangerous Liaison? A Literature Review," *JRC-IPTS Working Papers*, JRC76143, Institute for Prospective and Technological Studies, Joint Research Centre.

Schreyer, P., P. Bignon and J. Dupont (2003), "OECD Capital Services Estimates: Methodology and a First Set of Results", OECD Statistics Working Papers, 2003/06, OECD Publishing. http://dx.doi.org/10.1787/658687860232

Schreyer, Paul (2001); "Computer price indices and international growth comparisons", *Economics of Innovation and New Technology*, Vol. *10*.

Schreyer, Paul (2010), "Measuring Multi-Factor Productivity when Rates of Return Are exogenous," Chapter 2, pp. 13-40 in W.E. Diewert, B.M. Balk, D. Fixler, K.J. Fox and A.O. Nakamura (eds.), *PRICE AND PRODUCTIVITY MEASUREMENT: Volume 6* -- Index Number Theory. Trafford Press.

Severgnini, B. (2009), "Growth Accounting, ICT and Labour Demand", in Burda M. (*ed.*), *The Impact of ICT on Employment*, Humbold-Universitat zu Berlin.

Spiezia, Vincenzo and Marco Vivarelli (2002), "What Do We Know About the Effects of Information and Communication Technologies on Employment Levels?" in Greenan, N., L'Horty, Y., and Mairesse, J. (Eds.), *Productivity, Inequality, and the Digital Economy – A Transatlantic Perspective*, MIT Press, Cambridge, Mass.