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Productivity and growth in Europe

ICT and the e-economy

European Investment Bank

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Preface

In modern economies, GDP growth hinges not primarily on more labour and capital but on better capital, higher-skilled labour, and a growing ability to combine these inputs efficiently. To stimulate economic growth, it is essential to let domestic and international competition drive the reallocation of labour and capital across plants, firms, industries and even countries in search of more productive uses. The companion issue (Volume 16, Number 1) to this issue of the *EIB Papers* sheds light on this basic insight from various angles, drawing a number of important policy lessons.

Plutarchos Sakellaris
Vice-President

This issue (Volume 16, Number 2) returns to a core concern for the EIB: capital formation and its financing. It thereby zooms in on information and communication technologies (ICT). Here we expand on the themes of the 2009 *EIB Conference in Economics and Finance* and Volume 14 of the *EIB Papers*, which focused on R&D and innovation. That conference concluded that investment in R&D and the accumulation of human and other forms of intangible capital are major drivers of productivity growth. However, especially in advanced service-based economies, computers and telecommunication networks are instrumental for productivity growth in their own right. With EUR 24 billion in loans to ICT projects in the past decade, the EIB has an obvious interest in the field.

We now stand at the doorway of yet another technological leap: ultra-fast broadband. By promising to deliver great amounts of information to firms and households in a fraction of a moment, this technology can potentially reshape economic activity in dramatic ways. Universal broadband services feature prominently on the list of EU policy objectives. The "Digital Agenda for Europe" – one of seven flagship initiatives in the context of the Europe 2020 Strategy for smart, sustainable and inclusive growth – aims, among other things, at giving all European households access to very fast Internet connections (30 Megabits per second or more) by 2020. For most member countries, reaching this target implies substantial investment, raising eminent public-policy questions: Are the economic benefits large enough to justify the costs? Which share of total investment is the private sector likely to shoulder?

In assessing the potential economic benefits of the Internet in general and ultra-fast broadband in particular, one question is: Which new applications and businesses will come into existence and what will they do to long-term GDP growth? Taking this – admittedly more speculative – dynamic look is indispensable to understand the full implications of the Internet economy. Indeed, the welfare benefits extend beyond faster computation and cost savings from goods and services moved from physical to virtual markets. Perhaps the most radical consequence of the Internet economy consists in a lasting acceleration of the rate of technological change, leading to a lasting increase in the rate of sustainable GDP growth. Although the hyped-up talk of the e-economy reached its peak already a decade ago, the economic effects of this new general-purpose technology will last for many years to come.

I am confident that the research findings presented in this volume will further enhance our understanding of the channels through which ICT affects productivity and welfare and I am happy we can share them with you. I trust that they will also serve a wider audience in Europe and elsewhere.

Productivity and growth in Europe

ICT and the e-economy

The *2011 EIB Conference in Economics and Finance* – held at EIB headquarters in Luxembourg on October 27 – brought together academics, policy makers and companies to discuss productivity and Europe's long-term growth potential. It reviewed the empirical evidence on productivity growth and its drivers, with a particular focus on industrial structure and flexibility and discussed policies to boost productivity growth in Europe. The conference also zoomed in on the particular role of ICT and the e-economy for productivity growth.

Speakers included:

Erik BRYNJOLFSSON
of the Massachusetts Institute of Technology

Richard CAWLEY
of the European Commission

John HALTIWANGER
of the University of Maryland

Jussi HÄTÖNEN
of the European Investment Bank

Giuseppe NICOLETTI
of the Organisation for Economic Co-operation and Development

Gianmarco OTTAVIANO
of the London School of Economics

André SAPIR
of Bruegel

Hubert STRAUSS
of the European Investment Bank

Kristian UPPENBERG
of the European Investment Bank

Bruno van POTTELSBERGHE
of the Solvay Brussels School of Economics & Management

ABSTRACT

ICT capital is an important driver of productivity growth. *Using data from the EUKLEMS growth accounts, we show that ICT has made smaller contributions to labour productivity growth in the EU-15 than in the US, both at the macro level and at the level of individual sectors. At the same time, progress in productive efficiency – as measured by total factor productivity (TFP) growth – sharply declined in Europe and has remained weak since the mid-1990s whereas the US has seen acceleration in TFP. The near-stagnant TFP in market services in the EU-15 is particularly worrying. In both the EU-15 and the US, the growth contributions from ICT are found to be smaller than those from TFP. However, our empirical analysis suggests that the full effect of ICT capital on productivity is larger than what the growth accounts suggest because many ICT benefits occur with a delay.*

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The authors would like to thank, without implicating, Kristian Uppenberg, Timo Välilä, Jussi Hätönen and Andreas Kappeler for helpful comments and discussions. The views expressed in this article do not necessarily reflect those of the EIB.

ICT capital and productivity growth

Hubert Strauss

Besik Samkharadze

1. Introduction

Fostering economic growth has been high on the EU policy agenda for more than a decade. However, Europe as a whole has not delivered on its growth targets (*e.g.* as set in the Lisbon Strategy). While the EU had an impressive job creation record until the outbreak of the economic and financial crisis, productivity growth has suffered from a drawn-out slowdown (Uppenberg 2011). In the future, however, GDP growth will be about making the European workforce more productive given that employment growth will be more and more constrained by demographic ageing.

Growth in output – be it aggregate GDP or real value-added in individual sectors – is driven either by increases in employment or by increases in labour productivity. This paper focuses on labour productivity, thereby distinguishing between three types of contributions: more capital per worker ("capital deepening"), a more productive composition of the capital stock, and increases in economic efficiency (total factor productivity – TFP).[1]

As to the composition of the capital stock, information and communication technology (ICT) equipment is an asset type that has been found to make particularly large contributions to output growth (see *e.g.* Oliner and Sichel 2000; Jorgenson and Stiroh 2000; Stiroh 2002; Oliner *et al.* 2007). This is for at least three reasons. First, as a general-purpose technology, ICT enables efficiency gains in existing production throughout the economy. Second, the production of ICT equipment itself is subject to technological progress (*e.g.* higher processor speed) that is so rapid that users have seen significant price declines coincide with quality improvements for at least two decades. This implies persistent stimulus for ICT investment. Third, there are indications that ICT, by its versatility and widespread applicability could raise the pace of technological change and hence, GDP growth (Brynjolfsson 2011, in this issue).

Throughout the paper, we use the EUKLEMS database as our data source.[2] It is uniquely suited to analyze the growth effect of ICT capital across countries and sectors. EUKLEMS provides detailed breakdowns of outputs and inputs at the sector level, thereby distinguishing between nine types of capital – three ICT types (information technology equipment, communication technology equipment, and software) and six conventional types – and 18 types of labour, distinguishing between three levels of educational attainment, three age groups, and gender. Another attractive feature of the database is that it makes available long time series of hours worked, enabling a refined analysis of labour inputs. In the 2009 release version, the period from 1970 through 2007 is covered.

A major drawback, however, is that the time period covered (1970-2007) ends before the economic and financial crisis. We therefore are not able to cover the effects of the crisis on ICT and productivity.[3] Unfortunately, there is no solution to this problem. In fact, most statistical agencies do not even report ICT investment separately; the latter is lumped together with other non-transport machinery and equipment (Timmer *et al.* 2007).

1 Conceptually, the latter expresses by how much output grows at unchanged quantities of inputs because production becomes more efficient. In the empirical reality, TFP indices reflect both improvements in economic efficiency and data measurement errors.

2 The name "KLEMS" refers to capital (K), labour (L), energy (E), materials (M) and services (S), referring to EUKLEMS' unique quality of providing cross-country comparable sector-level annual data on gross output and value added, productivity, intermediate inputs, employment, capital formation, as well as growth accounts for EU countries, Japan and the US. Output and input measures are harmonized across countries, including harmonization of labour types and capital assets as well as measurement of capital stocks and services. See O'Mahony and Timmer (2009) and Timmer *et al.* (2007) for detailed descriptions of the EUKLEMS database and methodology.

3 For a brief discussion on how the Great Recession has affected GDP and its basic components (employment and labour productivity), one may refer to Uppenberg (2011).

To keep the amount of information manageable, our paper limits the discussion of capital deepening to the distinction between ICT and non-ICT. As far as labour inputs are concerned, we either report the overall labour composition effect on productivity (Section 2), or provide one basic distinction into high-skilled and low-skilled workers (Section 3). Moreover, while in principle, EUKLEMS provides input and output measures for 72 detailed sectors, growth accounting results are available for 31 broader sectors, hence this will be the lowest level of aggregation used in this paper. As a rule, we use the data published in the November 2009 release, except for the information on the share of hours worked by the high-skilled, which is taken from the March 2008 release (see EUKLEMS 2009).

We show the breakdown of labour productivity growth into contributions from (ICT-) capital-deepening, 'up-skilling' and TFP.

The paper is organized as follows. Section 2 presents a breakdown of labour productivity growth into its various contributors from a growth accounting perspective, thereby looking both at the total economy and at broad sectors. Moving beyond the growth accounting perspective, Section 3 analyzes the connection between ICT and efficiency, first by searching for lagged effects of ICT investment on TFP growth, and then by estimating a production function for a panel of 13 countries and 22 sectors for the period 1995-2007. Section 4 concludes and draws some policy implications.

2. The contribution of ICT investment to labour productivity growth: Growth-accounting evidence

This section provides a breakdown of labour productivity growth into contributions from capital deepening, improving labour composition and TFP growth from a growth accounting perspective. Our starting point is labour productivity (output per hour worked) rather than GDP, *i.e.*, we do not show the evolution of employment. In that sense, our paper is complementary to Uppenberg (2011) who illustrates and discusses the breakdown of GDP growth into contributions from employment and labour productivity across sectors in the US and Europe over the past three decades. We focus on the comparison between the US and the EU-15 as a whole (see Uppenberg 2011 for a detailed discussion of developments in 15 old and new EU countries).[4]

Throughout Section 2, we use the following framework (leaving out the sector subscript for simplicity):

(1) $$\hat{\lambda}_t = \alpha_I \hat{k}_{I,t} + (1 - \alpha_I)\, \hat{k}_{N,t} + \hat{Skill}_t + \hat{T}_t$$

where t is a time subscript and a hat denotes the annual growth rate. Equation (1) states that the growth rate of real value-added per hour worked (λ) is equal to the weighted sum of growth rates in ICT- (k_I) and non-ICT (k_N) capital[5] per hour worked, an effect from the changing skill composition of the workforce, and TFP growth. To weigh the growth rates of the two capital stocks, we use the share of ICT in total capital income, α_I, and the corresponding share of non-ICT capital, $(1 - \alpha_I)$. The labour composition effect ("Skill") is based on the idea that more educated or more experienced workers deliver more labour services (or efficiency units) per hour. So even if the total number of hours worked remains constant, the amount of labour services may nevertheless increase as workers accumulate experience and as higher-educated labour market entrants replace less educated retiring workers. The last contribution in Equation (1), TFP growth, is in fact a residual since it is equal to the difference between growth in real value-added and the sum of the first three contributions on the right-hand side.

With these preliminaries in mind, we show the respective contributions to labour productivity first at the aggregate level (Sub-section 2.1) and then at the level of broad sector groups (Sub-section 2.2) to find out to what extent the roles of ICT capital and productive efficiency (TFP) differ across sectors.

4 EUKLEMS growth accounts are only available for two of the ten new EU member states (Czech Republic and Slovenia), making representative statements on the drivers of productivity in Central and Eastern Europe impossible.

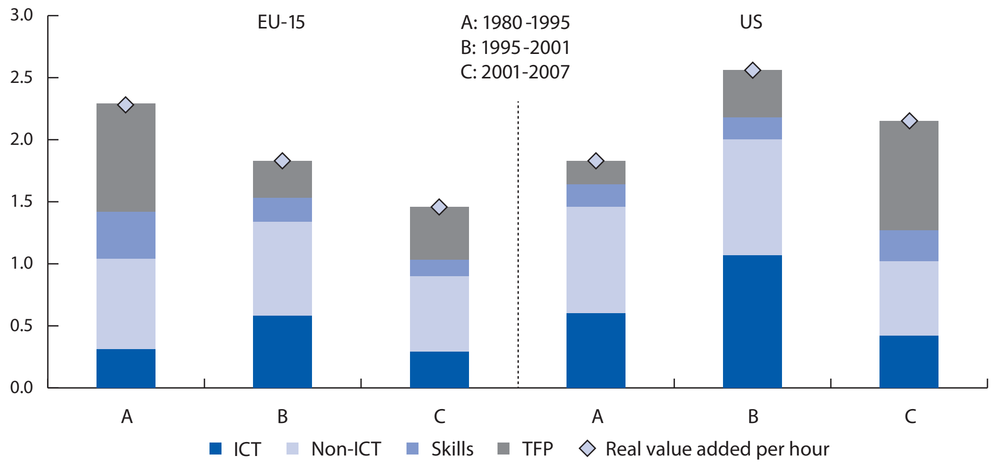
5 More precisely, EUKLEMS uses capital services (not stocks) to match the character of value-added and hours worked, which are flow variables. Since growth in capital services is proportional to growth in the capital stock for most sectors and countries, we use the terms "growth in capital stock" and "growth in capital services" interchangeably.

2.1 Total-economy perspective

Figure 1 depicts the decomposition of average annual labour productivity growth for the three periods 1980-1995, 1995-2001 and 2001-2007, with the left half showing results for the EU-15 and the right half the corresponding results for the US economy. Looking first at the EU-15, the figure gives three main messages. First, overall labour productivity growth has steadily declined, coming down to only 1½ percent per year in the last period. Second, ICT capital contributed half a percentage point (pp.) to annual productivity growth during the second period – spanning the ICT boom –before falling back to ¼ pp. And third, the temporary acceleration in ICT capital-deepening during the second half of the 1990s was too timid to compensate for the sharp drop in TFP growth. The latter hardly recovered during the 2000s.

Labour productivity growth has steadily declined in the EU-15 as the temporary wave of ICT investments in the 1990s was not enough to stem the decline in TFP.

Figure 1. Contributions to labour productivity growth in the EU-15 and the US
Total economy, average annual contribution (pp.), 1980-2007



Source: EUKLEMS

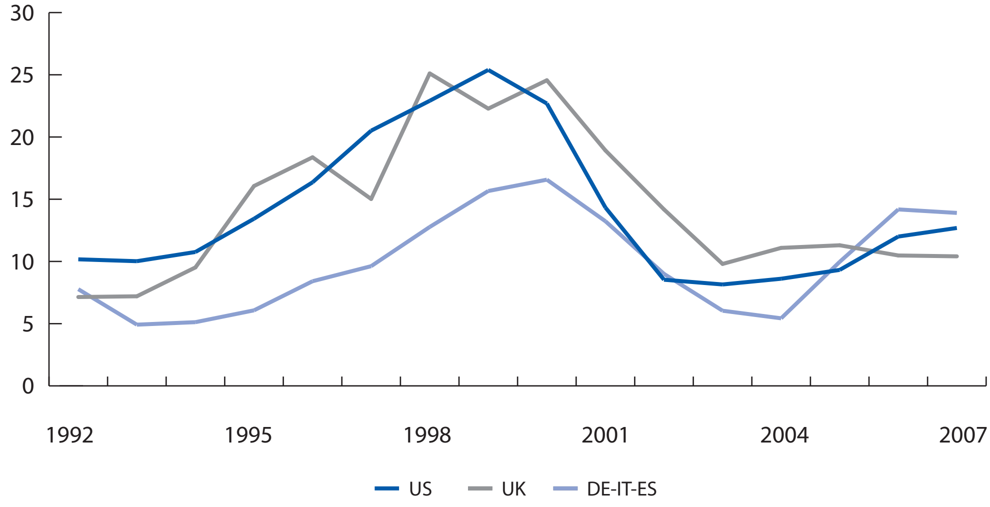
Notes: "pp." denotes "percentage point". The annual growth rate in real value-added per hour is an approximation. It is obtained by subtracting the contribution of hours worked from the growth rate of real value-added in the EU KLEMS growth accounting database. "Skills" refers to the labour composition effect on productivity, reflecting increases in the average education attainment and/or work experience. For the purpose of EUKLEMS growth accounting, EU-15 includes the following nine member states: Austria, Belgium, Denmark, Finland, France, Germany, Italy, Netherlands, and Spain.

In the US, by contrast, labour productivity growth accelerated during the 1990s, mainly due to rapid increases in ICT capital. ICT contributed a full percentage point to annual productivity growth in the second period, twice as much as in Europe. Moreover, the US has seen a striking increase in TFP growth after 2000 (the end of the ICT boom).[6]

The slowdown in the ICT contribution to productivity growth is for the largest part due to the slower pace of ICT investment after the burst of the dot-com bubble in 2000. Figure 2 shows the growth rate of the ICT capital stock in the US, the UK and major euro area countries (Germany, Italy and Spain). At the height of the ICT boom, annual growth rates peaked at 25 percent. Despite the marked slowdown after 2000, the ICT capital stock still expanded by more than 5 percent every year, *i.e.* faster than the stock of non-ICT capital.

6 Another peculiar (if quantitatively less important) US-EU difference is that growth contributions from upskilling (labour composition) increased slightly in the US but declined significantly in the EU-15 during the past three decades.

Figure 2. Growth in ICT capital stock, 1992-2007
Year-on-year percentage change, total economy



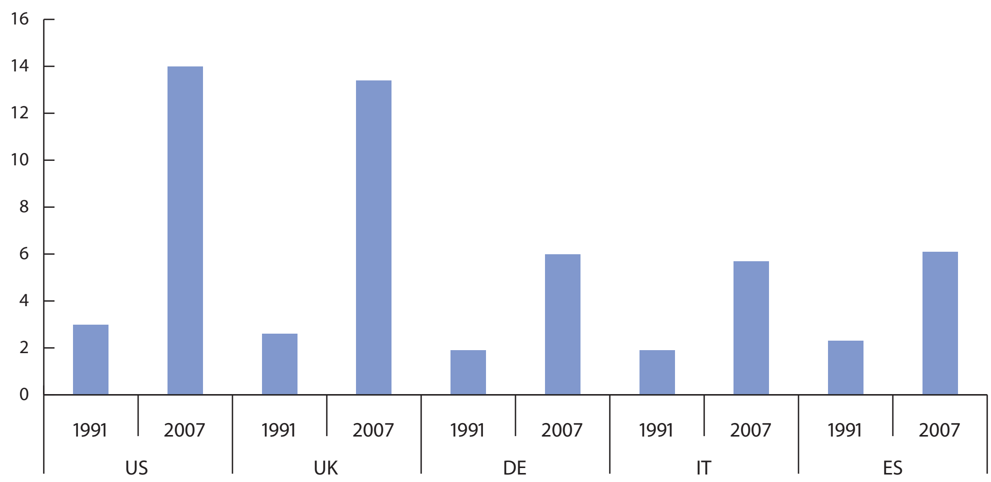
Source: EUKLEMS

There is a striking similarity between the ICT capital growth profiles of the US and the UK. Both are in stark contrast to the shallower expansion path in the major euro area countries where ICT capital growth rates peaked at 16 percent at the height of the dot-com bubble. The euro area outpaced the Anglo-Saxon partners only in 2006 and 2007 when the ICT capital expansion nearly matched its pace seen in the late 1990s.

From 1991 to 2007, the share of ICT in the aggregate capital stock tripled in Germany, Italy and Spain and it quintupled in the US and the UK.

As a result of the developments depicted in Figure 2, the share of ICT in the aggregate capital stock has increased substantially in virtually all economies, albeit at different speeds: while it tripled from 1991 to 2007 in Germany, Italy and Spain, it quintupled in the US and the UK (Figure 3). Since both countries already had a higher ICT share in total capital in the early 1990s, cross-country differences in the composition of the capital stock have become very large even for countries at similar levels of economic development. In 2007, ICT represented 14 percent of the economy-wide capital stock in the US and the UK, compared with only 6 percent in Germany, Italy and Spain.

Figure 3. Share of ICT in the capital stock of selected countries, 1991 and 2007 (percent)



Source: EUKLEMS

To some extent, this finding hides a "denominator effect": aggregate capital stocks are relatively smaller in the US and the UK, partly reflecting the more advanced stage of deindustrialization in these countries. Therefore, cross-country differences are somewhat less pronounced when the ICT capital stock is expressed as a fraction of GDP rather than the aggregate capital stock. The US and the UK thus have in common a smaller overall capital stock, yet one in which ICT plays a much bigger role than in continental Europe.

Why has the US economy invested more vigorously in ICT equipment than the EU? While a full-fledged discussion of the determinants of ICT investment is beyond the scope of this paper, Box 1 provides some answers that reflect a growing consensus in the economic literature. Over and above good ICT network infrastructure, a competition-friendly regulatory framework, high levels of co-investment in intangibles and sufficient availability of skills are all conducive to higher levels of ICT investment. What is more, each of these three elements has a direct influence on productive efficiency, too and might thus be the "third force" driving both ICT capital-deepening and TFP growth.

2.2 Sectoral perspective

We now turn to the sector evidence, focusing on the broad sectors manufacturing, "utilities" (NACE sector E – electricity, gas, water supply), construction, and market services.[7] We ignore agriculture and mining for their relatively small size in advanced economies. Despite being hugely important (one third of employment), non-market services are not shown either because productivity statistics are notoriously poor and value-creation processes still badly understood in this broad sector (see *e.g.* Timmer *et al.* 2010, pp. 257-259).[8] Given our focus on the business economy, the numbers shown in the following cannot be expected to "average up" to the total-economy evidence on labour productivity shown in Section 2.1. Furthermore, we concentrate on the two periods 1995-2001 and 2001-2007.

In manufacturing, a sharp acceleration in TFP growth more than compensated for slower capital-deepening, thus labour productivity soared.

Starting with manufacturing (left half of Figure 4), which represents roughly one fifth of total-economy value-added and employs one worker in six, this sector has seen its annual labour productivity growth accelerate somewhat in the EU-15 after 2000 (from 2 to 2½ percent) and substantially so in the US (to almost 5 percent). At first glance, the US record is surprising since the contributions from capital deepening (ICT and other) fell from somewhere around 1 pp. in the earlier period to essentially nothing after 2000. In both the EU and the US, the growth contribution of ICT capital stayed below that observed for the total economy in both periods, and the deceleration of the ICT contribution has been somewhat sharper. In fact, the manufacturing productivity revival in the US and in some parts of Europe is entirely due to the sharp acceleration in annual TFP growth (by 1 pp. in the EU-15 and by as much as 2.7 pp. in the US).

These trends have had a number of drivers. The deceleration of capital deepening and the acceleration of TFP may be seen against the backdrop of a wave of corporate restructuring after the burst of the dot-com bubble (see Uppenberg 2011 for a discussion of the revival in manufacturing productivity). Globalization is another central theme in this context. Rapid growth in international production sharing has resulted in pushing low-productivity manufacturers out of the market while favouring the expansion of high performers. This selection process accounts for the concomitant increases of internationalization and TFP at the sector level (Altomonte and Ottaviano 2011). Some authors also claim that higher TFP growth in the 2000s was the delayed benefit from innovation efforts as patent and trademark applications as well as investment in research and developement (R&D) scored high in the late 1990s (*e.g.* Dupont *et al.* 2009).

If manufacturing TFP has outgrown aggregate TFP since the mid-1990s, this can be partly traced back to the ICT-goods-producing sector. As depicted in the right half of Figure 4, US TFP growth in this sector

7 Detailed sector and country information on real value-added, capital and labour inputs and TFP is given in the Annex.

8 This sector is dominated by government-provided services (*e.g.* public administration, education and health), for which the absence of market prices in many countries prevents a meaningful distinction between outputs and inputs.

Box 1. Determinants of investment in ICT

To see what drives ICT investment, one should first consider the classical determinants of investment, foremost the cost of capital. In the case of ICT, another key is the high pace of quality changes, largely determined by advances in processor speed. Further, as users communicate over networks, benefits increase in the number of users (network externalities), enabling self-sustained increases in demand. As shown by Hätönen (2011, in this issue), the size and speed of communication networks have a strong impact on the development of new ICT-enabled services and thus, the demand for ICT.

However, as Guerrieri *et al.* (2010) put it, "ICT is a General Purpose Technology, its diffusion can be understood only by considering the interaction with institutional and structural factors". They find that changes in regulation, human capital and the sectoral composition of the economy are drivers of ICT investment at the macro-level in a panel regression for ten OECD countries for 1992-2005. In the following, we briefly review product market regulation; intangible capital and human capital and their connection with ICT investment, which is clearly visible in the data (*e.g.* Strauss 2011a).

On product market regulation, there is evidence that a lack of competition slows down price declines for ICT (Arnold *et al.* 2008). In addition, since new firms usually enter the market with newer equipment than incumbents and ICT equipment life-cycles are short, market entry is important for the dynamics of ICT-intensive sectors, especially in services. Accordingly, product market regulations that act as barriers to entry are relatively more harmful and translate into lower aggregate stocks of ICT. Moreover, as discussed in Arnold *et al.* (2011), anti-competitive regulations in essential services such as electricity, telecommunications and professional services reduce the incentives for productivity-enhancing innovations also in downstream sectors. They show that ICT-intensive sectors suffer more than others from over-regulated service input markets. All this suggests less ICT investment in highly regulated economies.

Regarding the link between ICT capital and innovation, the variability of inter-firm dispersion in productivity effects of ICT reflects firms' varying ability and willingness to make necessary intangible co-investments so as to exploit the full potential of ICT (Brynjolfsson 2011, in this issue), as will be further discussed in Section 2.3. Intangible investment is mostly innovation expenditure. Put simply, firms that re-organize business processes, train their workers on new ICT applications and implement new ICT-enabled ways of interacting with suppliers and customers reap larger productivity effects from ICT. Yet, this implies greater incentives to invest in ICT for those firms, sectors and countries that invest a greater fraction of their GDP in intangibles, implying the positive correlation between intangible investment and ICT investment. Countries like the US, Japan, Sweden and the UK have the highest expenditures on intangibles and are also among the countries with the highest ICT-investment-to-GDP ratios.

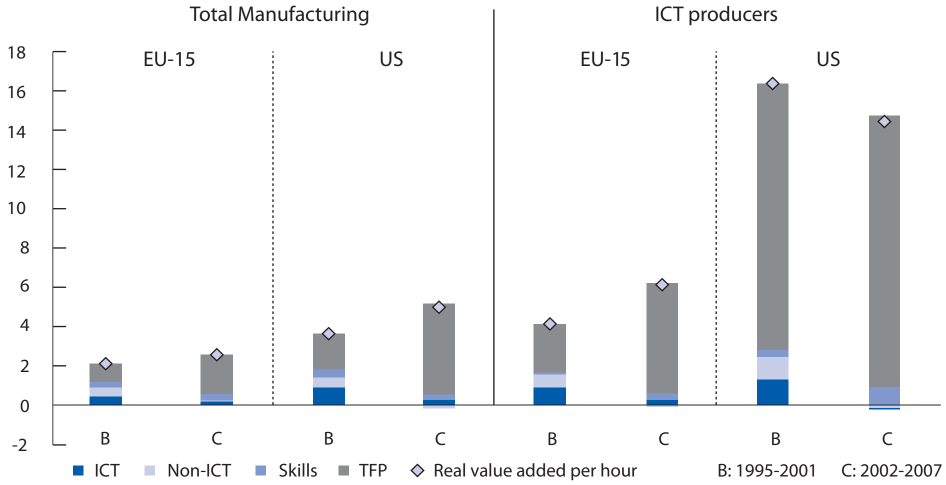
Finally, turning to human capital, empirical studies show that the demand for labour from the highest skill group has increased as a result of ICT, leading to a rising share of that group in employment and the wage bill, and *vice versa* for the lowest skill group (O'Mahony *et al.* 2008). ICT increases the demand for skills because implementing and using ICT systems requires a well-educated workforce. For example, expenditures required to train workers in new IT tools are arguably lower for highly-literate workers whose education prepares them for job variety and life-long learning.

One may also turn the direction of causality around and argue that technical progress and ICT adoption adjust to the availability of skills (*e.g.* Acemoglu 2002 who claims that the rapid up-skilling of the US workforce in the 1960s and 1970s made the US a privileged place for rapid high-tech capital adoption during the 1980s. As a matter of fact, the availability of high-skilled workers is a given. Changing this endowment *via* schooling or immigration takes time and is costly, so a shortage of high-skilled workers constrains ICT use.

There are thus supply as well as demand considerations to rationalize the positive correlation between economy-wide ICT investment and the share of the highly educated in the working-age population.

progressed at double-digit annual rates throughout. In Europe, TFP growth was much slower during the 1990s but picked up to 5½ percent after 2000. Rapid progress in chip-making (processor speed) goes a long way in explaining the stellar performance of US manufacturing.[9] Faster labour productivity growth implies that the ICT-producing sector's share in total-manufacturing output has kept rising: evaluated at 1995 prices, that share reached about one half in the US by the mid-2000s and one quarter in the EU-15, compared with employment shares of just one eighth and one tenth, respectively. While the contributions from ICT capital-deepening pale compared to the very large TFP growth, ICT capital contributed more to labour productivity in the ICT-producing sector than it did in other manufacturing sectors.

Figure 4. Contributions to labour productivity growth in the EU-15 and the US
Manufacturing, average annual contribution (pp.), 1995-2007



Source: EUKLEMS
Notes: See Figure 1. "ICT producers" in the right half refers to NACE sectors 30-33 (Electrical and optical equipment). It is part of Total manufacturing.

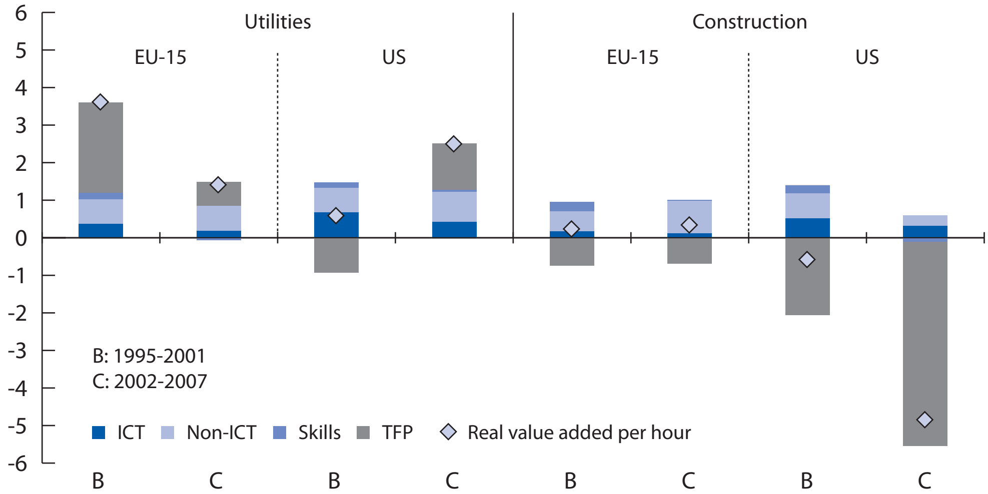
High productivity growth in utilities contrasts with stagnant or declining productivity in the construction sector.

Figure 5 shows the decomposition of labour productivity growth for utilities (left half) and for the construction sector (right half). Both these sectors have seen consistently smaller growth contributions from ICT capital-deepening than the economy as a whole, whether one looks at the EU-15 or the US. Utilities had better productivity growth performance in the EU-15 than in the US in the late 1990s, possibly reflecting efficiency-enhancing effects of regulatory reform. In the 2000s, EU-15 productivity growth slowed while it picked up in the US. In the construction sector, labour productivity, on average, nearly stagnated in the EU-15 and fell in the US, mildly until 2001 and at a worrying pace thereafter. On both sides of the Atlantic, a dismal TFP performance drives these outcomes while sub-par ICT capital growth further adds to the below-average annual growth in labour productivity.

We now turn to market services, which is by far the largest of the four broad sectors discussed in this sub-section. In 2008, the share of market services in aggregate employment was 43 percent in the EU-15 (up from 32 percent in 1980), compared with 46 percent in the US. Productivity performance in this sector thus carries an ever-larger weight for the growth prospects of the economy as a whole. The sharp contrast between weak labour productivity growth in Europe and sustained productivity gains in the US has sparked a lot of attention from researchers and policy advisors (see *e.g.* Inklaar *et al.* 2008; Timmer *et al.* 2010; Uppenberg 2011).

9 Sector "ICT producers" is larger than chip- and computer making alone. It also includes more traditional makers of electrical and optical equipment, which carry a larger weight in Europe, hence the less buoyant TFP expansion.

Figure 5. Contributions to labour productivity growth in the EU-15 and the US
Utilities and Construction, average annual contribution (pp.), 1995-2007

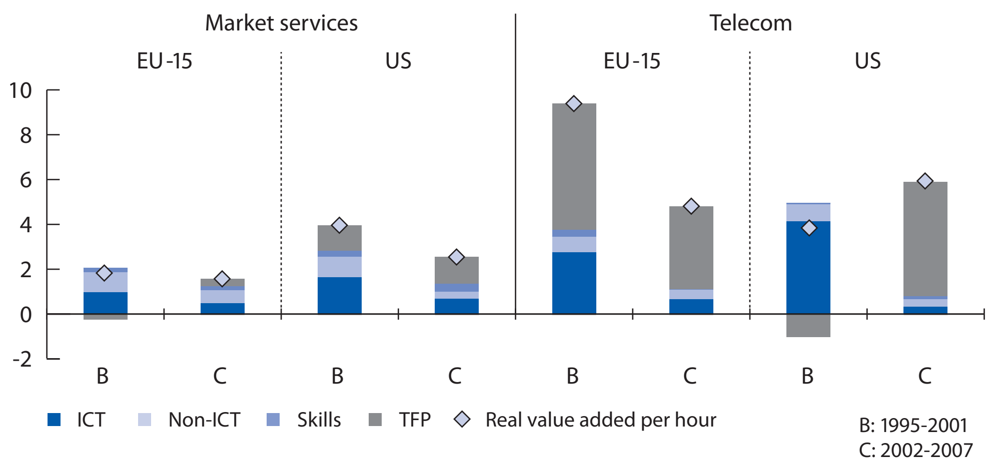


Source: EUKLEMS
Notes: See Figure 1.

In market services, the US combined strong ICT contributions with decent TFP growth while the EU-15 saw timid ICT adoption and no TFP growth.

Figure 6 (left half) illustrates this sharp transatlantic contrast. While labour productivity grew at rates between 1½ and 2 percent in the EU-15, it advanced at annual rates of 4 percent (1995-2001) and 2½ percent (2001-2007), respectively in the US. As a consequence, the US-EU productivity gap kept widening, albeit at a reduced pace after 2000. The US success rests both on swift ICT capital-deepening and TFP. Typical for market services, ICT made above-average contributions to productivity growth in both regions. As argued in Uppenberg and Strauss (2010), Europe's weak productivity record in services cannot be traced back to an overall under-investment problem. However, the composition of the EU capital stock in services is still more tilted towards non-ICT assets, implying relatively slow diffusion of ICT. Concomitantly, Europe has seen a dismal TFP performance over the past one and a half decades: the level of TFP in market services was not higher in 2007 than in 1995.

Figure 6. Contributions to labour productivity growth in the EU-15 and the US
Market services, average annual contribution (pp.), 1995-2007



Source: EUKLEMS
Notes: See Figure 1. "Market services" excludes Telecom.

One particularity of the EUKLEMS dataset is that the aggregate "Market services" does not include "Telecom", *i.e.* NACE sector 64 (Post and telecommunications). This sector is reported separately given its critical importance for the deployment of (new) ICT-enabled services and Internet penetration of households (see Hätönen 2011, in this Issue).[10] High productivity dynamics in this sector would likely have positive knock-on effects on the economy as a whole.

Average productivity growth in Telecom is shown in the right half of Figure 6 above. It shows that Telecom labour productivity growth in the EU-15 is a success story, making Telecom one of the few sub-sectors where Europe compares favourably with the US. Powered by swift ICT capital-deepening and very high TFP advances, labour productivity grew by 9 percent per year on average during 1995-2001 and still by half that rate in the later period as the ICT contribution fell to below 1 pp. per year while TFP held up relatively well. Telecom in the US, although investing heavily in ICT as well, did not experience any TFP gains during the 1990s but staged an impressive TFP revival during the 2000s, which might be linked to the preceding ICT investment boom.

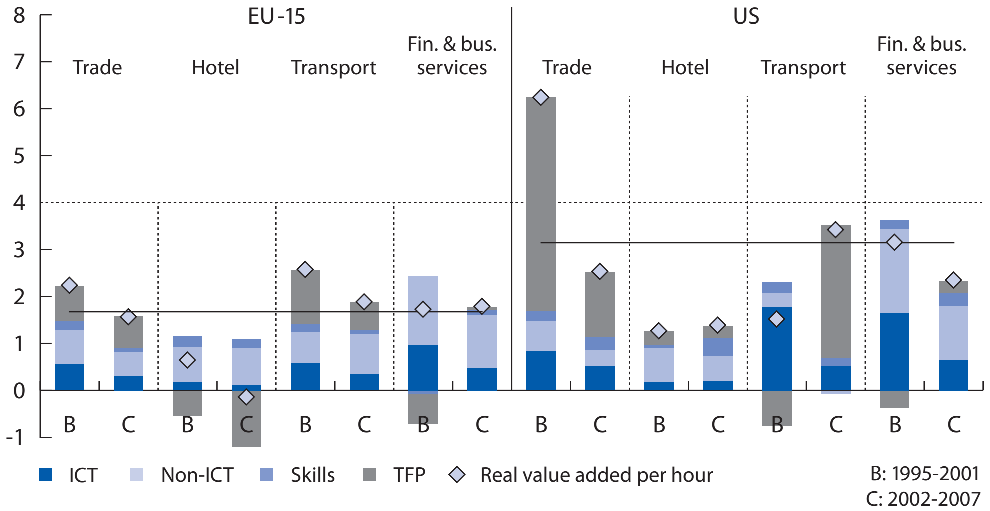
Productivity growth in Telecom is a European success story – one of the few sectors where Europe compares favourably with the US.

Market services consist of a number of sectors that are quite heterogeneous in terms of skill intensity and the type of capital (ICT *versus* non-ICT) they use intensively. This is why we conclude this sub-section by zooming back in on Market services (excluding Telecom) to discuss productivity developments in the following component sectors (2005 EU-15 employment shares in parentheses)[11]:

- "Trade": Wholesale and retail trade and repair (0.36);
- "Hotel": Hotels and restaurants (0.12);
- "Transport": Transport and storage (0.12);
- "Fin. & bus. services": Financial and business services (0.40).

Figure 7 illustrates labour productivity growth and its components for these sub-sectors and for each of the two periods, depicting EU-15 results on the left and US results on the right. The horizontal bar indicates average labour productivity growth in market services in each region for the entire 1995-2007 period, which allows putting the results into perspective.

Figure 7. Contributions to labour productivity growth in the EU-15 and the US
Market services sectors, average annual contribution (pp.), 1995-2007



Source: EUKLEMS
Notes: See Figure 1.

10 While the employment share of Telecom in total market services (EUKLEMS "Market services" plus Telecom) was only 2.8 percent, it's share in real value-added (at 1995 prices) amounted to as much as 11 percent, reflecting very high levels of value-added per hour.

11 See Annex for the corresponding NACE codes of each sub-sector.

Looking at the EU-15, three observations stand out. First, Transport outperforms the sector average while Hotel underperforms in terms of labour productivity. Second, growth contributions from ICT capital deepening were highest in Fin. & bus. services, lowest in Hotel and comparable with total-economy outcomes in the other sub-sectors. Third, Europe's dismal TFP performance in market services can be entirely attributed to Fin. & bus. services and Hotel, whereas Trade and Transport each posted solid annual TFP growth of between ½ and 1 percent. The dismal TFP performance in Fin. & bus. services is surprising insofar as that sector has increased its ICT capital stock more rapidly than other parts of the economy from 1995 to 2007.

The pattern of ICT capital-deepening and TFP growth being stronger in the US than in the EU-15 is remarkably consistent across sectors.

Turning to the US, the most striking difference from the EU-15 is the stellar productivity performance of Trade. Labour productivity in Trade progressed by more than 6 percent annually in the first and another 2½ percent in the second period, two thirds of which can be attributed to TFP. A second observation is that ICT capital-deepening has made larger contributions in the US than in the EU-15 across all sub-sectors, with the starkest difference seen in Transport. Finally, it is remarkable that sectors like Transport as well as Fin. & bus. services – but also Telecom shown above – which saw particularly strong ICT capital-deepening during the 1990s were able to accelerate TFP growth in the 2000s or at least to turn it around from negative to modestly positive growth contributions.

2.3 Main points and perspective

The main insights of Section 2 are that US productivity has outgrown the EU-15 mainly because of stronger ICT capital deepening and faster progress in productive efficiency (TFP). These two patterns are remarkably consistent across all sectors shown above even though they contributed to the growth gap to varying extents: While the US manufacturing revival is essentially a TFP story, faster US productivity growth in services reflects a combination of faster and deeper ICT diffusion and higher TFP growth. The single most remarkable (macro and sectoral) feature for the US is that TFP growth accelerated after 2000 even as ICT capital growth slowed down markedly.

The pick-up in US TFP growth following the wave of ICT investment in the late 1990s is no coincidence. Early firm-level studies find the productivity effects of ICT to be abnormally high on average – but with large dispersion across firms (for a survey see Stiroh 2004). Further studies, for example Brynjolfsson and Hitt (2000) and Brynjolfsson *et al.* (2002), find that the most successful firms are those which, following large-scale ICT investments, also devote significant resources to reorganizing their businesses. These efforts often cost a multiple of the new ICT equipment and the resulting efficiency gains may take years to materialize. When explicitly accounting for this additional intangible investment, returns to ICT are no longer found to be abnormally high.

At the sector level, Inklaar and Timmer (2007) show that the US economy enjoyed a sectorally more broad-based pick-up in TFP growth in the first half of the 2000s whereas dynamic TFP developments in the EU were a matter of a few sectors. This matches the fact, illustrated in this section that ICT diffusion in the US has not only been more intense for the economy as a whole but also for most individual sectors, including in sectors using ICT less intensively.

While it may be possible to account for intangible investment (*e.g.* expenditures for staff training and business reorganization) at the firm level, the national accounts treat the bulk of intangible investment as expenses. To the extent that it is exactly this omitted complementary investment that allows "wringing out" the full productivity potential of ICT, growth accounting is bound to deliver huge TFP contributions. It should be borne in mind, however, that some of these contributions have been triggered by ICT investment.

In recent years, empirical researchers have undertaken efforts to conceptualize and measure intangible investment and capital (Corrado *et al.* 2005, van Ark *et al.* 2009) for the (market) economy as a whole and to quantify their impact on labour productivity growth by way of enhanced growth accounting (*e.g.* Corrado *et al.* 2009). Indeed, these studies find that the share of the TFP contribution in average labour productivity growth shrinks thanks to this sophistication. Estimations of intangible investment and capital start coming into existence at the sector level too (*e.g.* Haskel and Pesole 2011) but are still rare and incomplete.

The reasons just discussed suggest that there seems to be a link between ICT capital-deepening and TFP that is worth investigating further, if only indirectly given the data constraints. This is done in Section 3.

3. The connection between ICT and TFP at the sector level

While growth accounting is useful, the approach has several weaknesses.

The growth accounting approach used in the previous section is a useful first step in linking growth in output to growth in inputs. It has, however, several weaknesses. A first weakness is that it links current growth in output to current growth in inputs. Thus, any delayed output and productivity effects from ICT capital-deepening "end up" in the TFP growth contribution of the periods following the ICT capital-deepening rather than being accounted for as ICT effects. It is therefore interesting to study the ICT-TFP correlation over time. We do this in Section 3.1.

Another set of weaknesses are the relatively restrictive assumptions made in growth accounting. First, as the true marginal contribution of each factor is not directly observable, it is assumed that the elasticity of real value-added with respect to each factor of production equals the income share of the factor, reflecting perfectly competitive input and product markets. Related to this is the assumption of constant returns to scale: the income shares of factors sum up to 100 percent and so must the input elasticities. In reality, it could well be that an increase in all inputs by, say 10 percent, increases real value-added by more (or less) than 10 percent, reflecting increasing (or decreasing) returns to scale. If the assumptions were violated, the growth contributions from ICT capital and TFP would be misrepresented. In Section 3.2, we therefore estimate the true input elasticities from an econometric model, which also allows testing whether returns to scale are constant. Since the model is multi-period and controls for the interdependence of input and output decisions, it is able to gauge the true, long-run effect of factor accumulation (*e.g.* ICT capital-deepening) on real value-added.

3.1 TFP growth and lagged ICT investment

To address the unduly contemporaneous focus of growth accounting, we now look at current TFP growth and lagged ICT capital-deepening. As a starting point, we use the fact that firm level studies have shown a positive correlation between firms' TFP levels and their ICT capital intensity. For example, Figure 4 in Brynjolfsson (2011, in this issue) shows strong correlation between US firms' TFP levels and their ICT capital intensity (both relative to sector average).

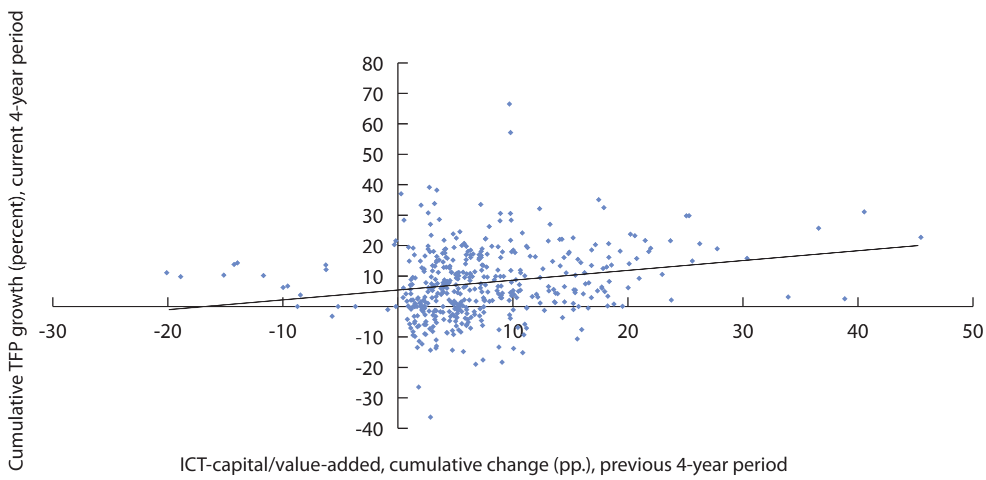
It is natural to ask whether this correlation holds at the industry level, too. We cannot answer the question directly since in the EUKLEMS dataset, TFP is an index that equals 100 in the base year (1995), so all historical differences across countries and sectors in the level of productive efficiency are wiped out. To circumvent the problem, we look at cumulative changes in ICT capital intensity and cumulative changes in the TFP index.

Motivated by the finding of ICT adoption costs in the management literature, some authors suggest that one should, if anything, expect a positive correlation between *lagged* ICT capital-deepening and TFP growth. Basu and Fernald (2007) use current ICT capital intensity and past ICT capital growth as a proxy for unmeasured intangible co-investment to ICT investment. They find that TFP in the early 2000s indeed followed the ICT investment wave of the 1990s with a considerable lag (5 years or more). They show that when controlling for past ICT investment, the contemporaneous correlation between TFP and ICT investment becomes significantly negative, reflecting that resources are temporarily diverted from current production to implementing new ICT equipment.

In ICT-using sectors, there is a positive correlation between TFP growth and past ICT investment.

Figure 8 shows the connection between cumulative TFP growth (EUKLEMS data) over the past 4 years and the cumulative growth rate in ICT capital observed during the preceding 4-year period for 13 countries and six rolling 4-year periods within the sample period (1995-2007), focusing on sectors that use ICT intensively (following the classification by Inklaar *et al.* 2005, see end of Section 3.2). There clearly is a positive correlation between TFP and past ICT investment in ICT-using sectors even though it is less than perfect.[12] We suspect business services, which have been shown in Section 2 to combine strong ICT investment with declining TFP, to blur the picture. Indeed, taking business services out makes the cloud of points look more conclusive and makes for a steeper regression line (results not shown).

Figure 8. Past ICT capital-deepening and average TFP growth in ICT-using sectors



Source: EUKLEMS

Notes: Each dot plots the cumulative percentage growth in the TFP index over four years (*e.g.* 2001-2005) of an industry using ICT intensively (*e.g.* machine-tool production) against the cumulative change (in percentage points) in the ICT-captial/value-added ratio during the preceding four-year period (1997-2001 in this example).

3.2 The ICT-elasticity of output and intersectoral differences in trend TFP growth

Following up on the second set of weaknesses of growth accounting exercises, we now relax the overly restrictive assumptions of constant returns to scale and perfect competition. We estimate the marginal

12 Unlike the pattern shown in Figure 8, the correlation coefficients between past growth in the ICT capital stock and TFP are found to be negative for the group of non-ICT-using sectors and zero for ICT-producing sectors, respectively (results not shown). Moreover, and in line with Basu and Fernald (2007), we could not detect any positive correlation between TFP growth and contemporaneous ICT capital growth for any of the three groups of sectors (ICT-using, non-ICT-using, ICT-producing sectors).

productivity of ICT capital and other inputs from an empirical model, rather than relying on factor income shares from the national accounts.

To illustrate why the simplifying assumptions of the growth-accounting exercise of Section 2 might be problematic, assume, first, that the elasticities of real value-added with respect to both ICT capital and high-skilled labour were higher than the respective shares of these factors in total factor income. As a consequence, the contributions to productivity growth of both ICT capital-deepening and skills reported above would understate their true contributions, because any increase in ICT capital and in high-skilled hours worked would deserve higher weights than they get in growth accounting. Second, assume that the sum of the output elasticities exceeded one, reflecting increasing returns to scale (*i.e.*, an increase in all input quantities by 1 percent would lift real value-added by more than 1 percent). As a consequence, the true contributions from both types of capital and up-skilling, taken together, would be higher than the sums shown in the figures of Section 2. In both cases, the contribution from TFP would shrink.

To answer the question whether the ICT contributions and the up-skilling contributions shown above are too small, we estimate a production function for a panel of 13 countries and 22 sectors spanning the years from 1995 to 2007, distinguishing between ICT- and non-ICT capital on the one hand and high-skilled labour (*i.e.* hours worked by higher-education degree holders) and other labour on the other. We do not constrain the input coefficients; hence, the constant-returns-to-scale assumptions can be directly tested for. Table 1 shows the results while Box 2 provides the details on the theoretical framework, specification choices, variables and results.

Table 1. Estimated output elasticities *versus* average factor-income shares

Inputs	Income share (GA)	Estimated output elasticity
High-skilled labour	0.109	0.135***
Low-skilled labour	0.569	0.473***
ICT capital	0.048	0.060 *
Non-ICT capital	0.274	0.330***
Total	1	0.998

Notes: Income shares are simple averages (cross-country, cross-sector and across-time) of the corresponding factor's share in gross income taken from the EUKLEMS growth accounting (GA). Output elasticities are from the Cobb-Douglas production function model estimated using Sys-GMM as described in Box 1.

Indeed, the table suggests that ICT and high-skilled labour make contributions to output in excess of their respective remuneration (factor income share). The same is true for the contribution of non-ICT capital. While the difference between the estimated elasticity and the income share is modest for ICT capital and possibly not statistically significant, the pattern is much clearer for non-ICT and human capital. Taken together, the results suggests that the "true" sum of contributions to productivity growth from capital inputs and skills are somewhat larger than those depicted in Section 2. Accordingly, the true TFP contributions are smaller.

ICT and high-skilled labour make contributions to output in excess of their factor income shares.

That being said, imposing constant returns to scale, as growth accounting does, does not appear to exacerbate the underestimation problem. Indeed, the sum of the elasticities reported in Table 1 amounts to 0.998, meaning that its deviation from one is not economically important.

Box 2. ICT, skills and output: Econometric evidence for a panel of 13 countries and 22 sectors

Production-theoretical framework. This box draws on Samkharadze and Strauss (2011). While we owe many ideas to Spiezia (2011), our specification choices deviate from his in several important respects. We start from a neoclassical production function relating real value-added (Y) to capital and labour:

(B1) $$Y_{ijt} = A_{ijt} F(K_{ijt}, L_{ijt}), \quad i = 1,\dots,N, j = 1,\dots, M, t = 1,\dots,T$$

where A is Total Factor Productivity (TFP) and i, j and t index country (N=13), sector (M=22) and time (T=13); respectively. In our specification, we distinguish between ICT (K^I) and non-ICT capital (K^N). Moreover, we split labour into hours worked by two distinct skill groups of persons: high-skilled (L^H) and low-skilled, *i.e.* all other labour (L^L). A Cobb-Douglas production function is chosen and estimated in log-linear form. It satisfies the conditions of monotonicity and quasi-concavity and its individual coefficients can be directly interpreted as factor specific elasticities. However, it is a restrictive functional form insofar as the elasticities are assumed to be constant.

Since TFP is not observable, we assume it to grow with time, permittedly at different rates of growth across countries and sectors. The inclusion of the country-specific time trend captures the extent to which country-specific policies and institutions affect the economy. In turn, the inclusion of the sector time trend captures sector-specific advances in technology and efficiency, assuming that these advances have the same long-run effect on all countries in the sample, *i.e.*, innovations and best practice are allowed to flow across borders in the long run. Unlike Spiezia (2011), we do *not* interact the two sets of time trends, which would allow for maximum flexibility but requires estimating some 300 coefficients. Therefore, to the extent that our assumption of international technology transfer is violated and national policy settings have a differential impact across sectors, our trend TFP estimates might match the data less than perfectly.

Taking into account the sub-aggregates of the production factors, the Cobb-Douglas production function in log-linearized form and our time-, country- and sector-dependent specification of TFP growth, Equation (B1) can be rewritten:

(B2) $$\ln Y_{ijt} = \beta_1 \ln K^I_{ijt} + \beta_2 \ln K^N_{ijt} + \beta_3 \ln L^H_{ijt} + \beta_4 \ln L^L_{ijt} + \alpha_{1i}\, time^C_{it} + \alpha_{2j}\, time^I_{jt} + \varepsilon_{ijt}$$

where $time^C_{it}$ denotes the country-specific time trend, $time^I_{it}$ the sector-specific time trend and ε_{ijt} is the error term. The coefficients α_{1i} and α_{2j} can be interpreted as the annual growth rates of TFP within each country i and sector j, respectively, *relative* to the one country (Austria) and the one sector (food-processing) dropped from the estimation.

Specification issues. Two econometric problems arise in estimating Equation (B2): endogeneity (production planning concerns inputs and outputs jointly); and heteroskedasticity, *i.e.*, the error term might not be independently and identically distributed as its variance may vary across countries/sectors/years. The first problem is commonly addressed by instrumental variables (IV) estimation, using lagged values of the endogenous variables as instruments. This technique often leads to an efficiency-size trade-off: satisfactory instrument quality requires long lags, which reduce sample size. To address endogeneity and heterogeneity concerns, we use the Arellano-Bover (1995)/Blundell-Bond (1998) system-GMM estimator, which is suitable for panels (as ours) with a low number of time periods and higher number of individual groups. It estimates a stacked system of first-difference and level equations using two sets of instruments – lagged levels in the first-differenced equation and lagged first differences in the level equation. The Sys-GMM circumvents the efficiency-size trade-off by employing "GMM-style" instruments (one for each variable and time period), resulting in a significantly higher instrument count. To avoid "over-fitting" problems (Roodman 2006), we keep the number of instruments far below the number of groups. Sys-GMM is also able to solve the second problem: it produces a robust estimator of the parameter covariance matrix, with standard errors consistent under heteroskedasticity and within-group autocorrelation (albeit not cross-sectional autocorrelation).

Data and variables. The data source is EUKLEMS, 2009 release. Quantity indices (1995=100) are derived from all output and input variables, then their log is taken. For real value-added, we directly take the EUKLEMS quantity index of real value added. For capital, the underlying time series is the real stock of ICT and non-ICT capital, respectively (in euros at 1995 prices). For high-skilled labour, it is total hours worked times the share of high-skilled labour in total hours (taken from the 2008 EUKLEMS release). For low-skilled labour, it is total hours worked minus high-skilled hours worked. Hence, the quantity indices on the input side are based on "physical units" for each sub-category rather than on capital or labour services measures (as *e.g.* in Spiezia 2011). The reason is that these aggregate services concepts weigh together different types of labour (capital) by using observed differentials in average wages (rental prices) that might not adequately reflect true productivity differences due to *e.g.* productivity and learning spillovers from high- to low-skilled workers. The Annex shows average levels of the (non-logged) output and input indices.

As a result of setting all outputs and inputs equal to 100 in 1995, cross-country differences in size and efficiency (*i.e.* output-to-input ratios) are wiped out. Any existing historical differences in TFP *levels* are thus lost. The interpretation of our results is therefore strictly in terms of (cumulative) growth (within or across countries/sectors) rather than cross-country/sector differences in output and productivity levels. We are thus not concerned by unobserved time-invariant country- and sector-specific effects affecting output and productivity *levels*. To the extent that such unobservables matter for *growth rates*, those effects are captured by the country- and sector-specific time trend variables. Also, the Sys-GMM removes the fixed effects by applying the first-difference transformation to Equation (B2).

Results. We implement the one-step Sys-GMM estimation proposed in Bond *et al.* (2001) rather than a two-step procedure because its asymptotically robust standard errors are more reliable in finite samples. We limit the instrument count by "collapsing" GMM-style instruments into columns and *via* economic reasoning. For example, ICT capital is "short-lived", justifying a low number of lags (we only use the second lag). By contrast, other types of physical capital are longer-lived and thus highly persistent, hence we use all available lags. Further, we use the second to fourth lags for the labour variables. The final instrument count equals 67, much below the number of groups (286).

Table B1 reports estimated coefficients, standard errors and diagnostics for the Sys-GMM model. As discussed in the main text, the output elasticities are sensible. They are all significant at the 1-percent level except for ICT capital, which is significant at the 10-percent level. The sum of input coefficients is close to one and the formal test of constant returns is not rejected at the 5-percent significance level. The lower half of Table B1 reports tests of some of the conditions for the Sys-GMM results to be reliable. The Arrelano-Bond test result suggests freedom of residual autocorrelation. Moreover, the Hansen test indicates that the over-identifying restrictions are valid even though the Sargan test does not. Yet, we primarily rely on the former because, unlike the latter, it is robust to any remaining heteroskedasticity and autocorrelation.

Table B1. Sys-GMM estimation results and diagnostics
Dependent variable: log of real value-added (Index 1995=100)

High-skilled labour	Low-skilled labour	ICT capital	Non-ICT capital	Sum of coeff. [CRS test]	Number of observations
0.135*** (0.047)	0.473*** (0.079)	0.060* (0.036)	0.330*** (0.078)	0.998 [0.096]	3,674
Residual autocorrelation test		Tests for validity of over-identifying restrictions			
Arrelano-Bond (AR(2))		Hansen (robust)		Sargan	
z-value	1.50	Chi2(18)	25.75	Chi2(18)	87.49***

Notes: Robust standard errors in parentheses, p-values in brackets; *, ** and *** denote significance at the 10, 5 and 1-percent level.

Table 2 provides the estimated results for the country- and sector-specific time trends. The coefficient of a sector-specific time trend may be interpreted as the sector's annual TFP growth relative to that of the omitted sector (Food processing) in a given country. Likewise, the coefficient of a country-specific time trend expresses the country's annual TFP growth relative to that of the omitted country (Austria) in a given sector. Following Inklaar *et al.* (2005), the 22 sectors are grouped into three aggregate categories – ICT-producing sectors, ICT-using sectors and non-ICT-using sectors – for which we calculate a simple average of the estimated coefficients across the constituent sectors.

Trend TFP growth rates vary considerably across ICT-using sectors, being high in Trade but low in Financial and business services.

Table 2. Relative trend TFP growth across sectors and countries
Estimated coefficient

Sector	Coefficient	Standard error	Country	Coefficient	Standard errors
ICT-using sectors	(0.012)		EU-15	(-0.006)	
Paper and Publishing (21-22)	0.013**	0.005	Austria	—	—
Other machinery (29)	0.012**	0.005	Denmark	-0.018**	0.006
Other manufacturing (36-37)	0.008*	0.005	Finland	0.013*	0.007
Sale of motor vehicles and fuel (50)	0.004	0.008	Germany	-0.003	0.006
Wholesale trade (51)	0.021***	0.006	Italy	-0.018**	0.006
Retail trade (52)	0.012*	0.006	Spain	-0.018**	0.006
Financial services (J)	0.03***	0.007	Sweden	0.001	0.008
Business services excl. real estate (71-74)	-0.002	0.005	Netherlands	-0.002	0.006
ICT-producing sectors	(0.052)		UK	-0.004	0.005
ICT goods production (30-33)	0.057***	0.014	Czech Republic	0.002	0.009
Telecom (64)	0.046***	0.008	Slovenia	0.006	0.011
Non-ICT-using sectors	(0.010)		Japan	-0.005	0.007
Food processing (15-16)	—	—	US	0.003	0.006
Textiles and footwear (17-19)	0.005	0.005			
Wood and cork (20)	0.011**	0.005			
Chemicals (24)	0.026***	0.005			
Rubber and plastics (25)	0.016**	0.008			
Other non-metallic minerals (26)	0.016***	0.005			
Metals (27-28)	0.008	0.005			
Transport equipment (34-35)	0.024**	0.008			
Electricity, gas, water (E)	0.022**	0.007			
Construction (F)	-0.01*	0.006			
Hotel (H)	-0.013*	0.007			
Transport (60-63)	0.004	0.005			

Notes: Robust standard errors in parentheses; *, ** and *** denote significance at the 10, 5 and 1-percent level, respectively. Cells in bold indicate sector or country groupings for which the reported relative TFP growth is a simple average of the estimated coefficients of the component sectors or countries.

The trend coefficient estimates reveal the following results. For one thing, the values confirm the stellar TFP growth performance of the ICT-goods and ICT-service-producing sectors (annual growth by 5.2 pp. in excess of TFP growth in food-production). For another, it suggests that TFP growth is indeed higher in ICT-using sectors (1.2 percent faster than in food production) than in sectors that use ICT less intensively (1 percent).

The difference is, however, surprisingly small. This is partly because even within the group of ICT-users, sectors are still quite heterogeneous. While Trade displays strong TFP gains, the business services sector – already identified as a weak performer in Sections 2.2 and 3.1 – is found to have a negative (if insignificant) trend coefficient. The financial industry, by contrast, has a significantly positive trend coefficient of 3 percent. Given the much greater size of the business services compared with the financial services sector, the two coefficients taken together are roughly consistent with the growth accounting result of positive but weak TFP growth in the period 1995-2007 (see Figure 7). At the same time, the average trend TFP growth in non-ICT-using sectors is pulled up by two R&D-intensive sectors: Chemicals and Transport equipment.

Further, the results suggest that the average annual TFP growth has been higher in the US and the new EU member states (Slovenia and Czech Republic) than in Japan and the EU-15. Within the EU-15, the only countries with significant country trend coefficients are Denmark and Finland (positive TFP growth) on the one hand and Italy and Spain (negative TFP growth) on the other.

All in all, Section 3 shows, first, that TFP growth and ICT capital-deepening are linked in time as productivity effects of ICT take several years to materialize. Second, our empirical analysis suggests that the marginal productivity of ICT capital and non-ICT capital is larger than their respective shares in factor income, and that skilled labour is substantially more productive than what is reflected in the share of the high-skilled in domestic income. Finally, our estimates show that trend TFP growth varies substantially across sectors and countries.

4. Conclusions and policy implications

ICT capital is an important driver of productivity growth. Using data from the EUKLEMS growth accounts, this paper has shown that ICT has made smaller contributions to labour productivity growth in the EU-15 than in the US, both at the macro level and at the level of individual sectors. At the same time, progress in productive efficiency – as measured by total factor productivity (TFP) growth – sharply declined in Europe and has remained weak since the mid-1990s whereas the US has seen acceleration in TFP. The near-stagnant TFP in market services in the EU-15 is particularly worrying. In both the EU-15 and the US, the growth contributions from ICT have been found to be smaller than those from TFP.

Our empirical analysis at the sector level has suggested that weak ICT capital accumulation may impair labour productivity growth by more than is suggested by growth accounting. For one thing, TFP growth and ICT capital-deepening are linked in time as many of the benefits from ICT adoption only materialize with a time lag and are thus recorded as TFP. For another, the marginal productivity of ICT capital is larger than its share in total factor income.

The policy implications of this paper are as follows. As suggested by our brief discussion of the determinants of ICT investment (see Box 1) and the conspicuous connection between (past) ICT capital deepening and medium-term TFP growth, policies that foster productive efficiency would most likely boost economy-wide ICT diffusion, too. Accordingly, competition-friendly product market reforms and a high-quality education system are key in stimulating productivity growth both directly and *via* ICT capital deepening. Public action to build innovation-friendly societies by stimulating entrepreneurship and experimentation and by removing barriers to mobility and resource reallocation would give an additional impetus to productivity growth in Europe (see Strauss 2011b for a summary).

Policies to foster productive efficiency – product market reform, better education and fewer barriers to mobility – would boost economy-wide ICT diffusion, too.

By contrast, we do not see a role for specific sector policies targeting the use of ICT. That being said, it is in the government's responsibility to ensure that ICT-enabling infrastructure networks be provided at sufficient size and quality. Over and above a stable, predictable and investment incentive-compatible regulatory framework, this may require targeted public support to network deployment in less profitable geographic areas (see Hätönen 2011).

Annex

Table A1. Sectoral levels of real value-added, capital stocks, hours worked and TFP, average 1995-2007
Indices (1995=100)

	Sector	Real value-added	High-skilled labour	Low-skilled labour	ICT capital	Non-ICT capital	TFP
ICT-using sectors	Paper and Publishing (21-22)	112	120	92	249	113	106
	Other machinery (29)	116	127	96	247	119	108
	Other manufacturing (36-37)	111	136	95	252	112	108
	Sale of motor vehicles and fuel (50)	120	139	108	280	126	103
	Wholesale trade (51)	131	128	102	314	121	113
	Retail trade (52)	125	126	102	289	124	114
	Financial services (J)	126	129	96	281	105	107
	Business services excl. real estate (71-74)	136	153	128	372	152	93
ICT producers	ICT goods production (30-33)	193	122	98	253	135	164
	Telecom (64)	164	171	98	294	135	122
Non-ICT-using sectors	Food processing (15-16)	103	135	94	218	113	99
	Textiles and footwear (17-19)	87	111	75	192	95	109
	Wood and cork (20)	114	123	94	254	115	110
	Chemicals (24)	126	122	94	231	117	115
	Rubber and plastics (25)	141	132	105	289	129	113
	Other non-metallic minerals (26)	113	119	93	220	108	111
	Metals (27-28)	113	127	100	240	112	105
	Transport equipment (34-35)	137	129	97	246	127	120
	Electricity, gas, water (E)	111	114	85	211	107	108
	Construction (F)	110	132	110	347	127	96
	Hotel (H)	109	146	110	295	117	95
	Transport (60-63)	116	129	104	239	128	102
	Country						
	Austria	122	148	98	419	104	117
	Czech Republic	149	114	103	314	141	116
	Denmark	112	132	100	401	113	99
	Finland	126	117	106	238	106	119
	Germany	138	103	92	171	107	110
	Italy	107	126	101	250	117	100
	Japan	109	111	87	154	108	103
	The Netherlands	106	153	99	276	110	111
	Spain	123	185	114	267	133	97
	Slovenia	132	114	97	156	161	117
	Sweden	137	152	97	189	130	121
	UK	117	128	94	297	115	107
	US	124	110	97	286	115	113

Source: EUKLEMS; own transformations based on EUKLEMS (columns 2 to 5)

Notes: The sector (country) numbers reflect simple cross-country (cross sector) cross-time averages of the corresponding sector (country) index. The sample period is 1995-2007 for all countries except for Japan and Slovenia (2006). Sectors are given short names as in the main text. The NACE code (rev. 1) is provided in parentheses. The table does not provide detail for sectors not used in the regression in Section 3.2, *i.e.* Agriculture (A), Fishery (B), Mining (C), Coke and fuel refinery (23), real estate (70), and social services (L to Q).
While the first five data columns are based on the indices used in the regressions of Section 3 (see Box 2), the TFP indices in the last column are those from the EUKLEMS growth accounting results discussed in Section 2.

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ABSTRACT

Europe is lagging behind other developed economies in the availability and use of very fast broadband services. *The recently introduced Digital Agenda for Europe initiative sets forward ambitious targets for the development of super-fast broadband infrastructures in Europe to foster smart and sustainable growth. This paper presents estimates of the costs of meeting these targets through the deployment of next-generation networks. Furthermore, the magnitude of the financing gap is estimated and public support mechanisms are discussed to complement market investment in areas with low financial viability for the investment. The rationale of public sector support is discussed in light of the expected economic benefits of NGNs to consumers and businesses.*

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The economic impact of fixed and mobile high-speed networks

Jussi Hätönen

1. Introduction

With over 2 billion subscribers worldwide, the Internet has become a necessity of modern societies. Along with the growth of use, Internet has evolved into an important economic activity. In fact, with an average 3.4 percent contribution to GDP, Internet-related activities have already a greater weight than education (3.0 percent), agriculture (2.2 percent) or utilities (2.1 percent), and an only slightly smaller weight than, for example, transportation (3.9 percent). Furthermore, it is estimated that Internet has contributed to 21 percent of GDP growth in the last five years in advanced economies (Rausas *et al*. 2011). In several countries, Internet is in fact classified as a universal service. Accordingly, network operators are obliged to provide this service to every inhabitant similar to electricity and roads.

Internet has evolved greatly since its introduction at the beginning of the 1990s, driven by developments in network technologies constantly allowing new services and solutions to be provided over the Web. In the past few years there has been increasing discussion on what is referred to as next generation Internet networks. Next generation access networks (NGN or NGA) refer to mobile and fixed-line networks enabling much higher access speeds than "traditional" networks. In Europe this discussion was recently further accelerated by the introduction of the Digital Agenda for Europe, one of the seven flagship initiatives of the Europe 2020 strategy and which puts forward ambitious targets calling for development of next generation super high-speed networks in the EU. The justification of these networks is often wrapped around economic benefits. Friedrich *et al.* (2009), for instance, state that "next generation national broadband networks can significantly improve the way that consumers, businesses, and governments interact, spurring economic growth and productivity", and that "governments must play a role in the deployment of such networks to overcome the hurdles that cannot be addressed by the private sector". In fact, it is widely acknowledged that due to the high cost of deploying NGNs, a high level of public support and intervention is called for. Policy makers have, in light of the Digital Agenda, initiated a discussion on how the governments should support the deployment of such networks – basing the need for them on high expected economic benefits.

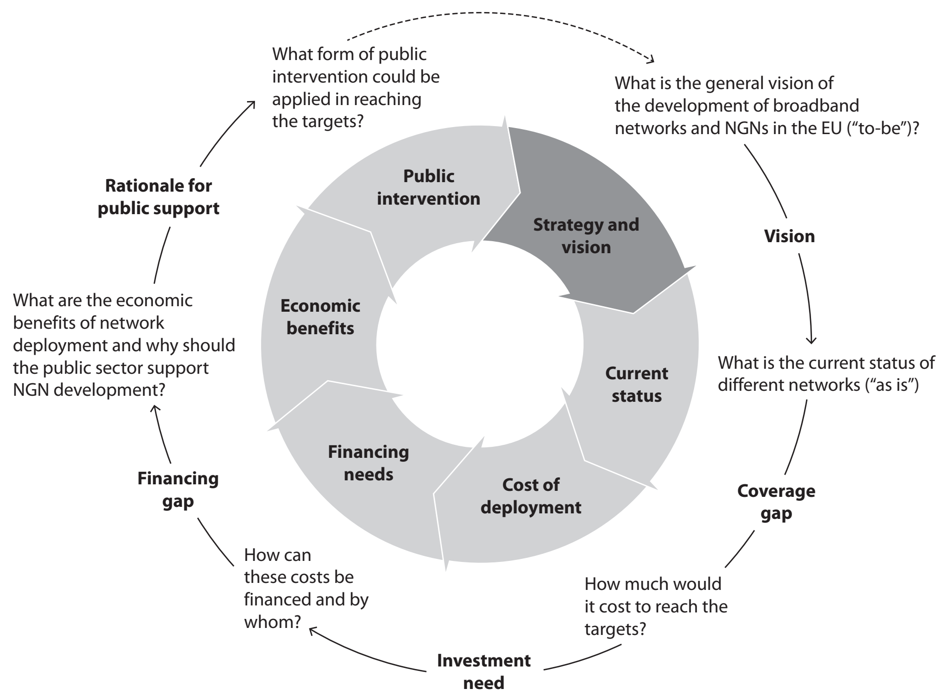
Despite an extensive literature on NGNs, much still remains unknown. Firstly, in the context of the EU, some initial attempts have been made to assess the total cost of implementing the Digital Agenda targets, yet they have mainly focused on a single technological scenario building on aggregate level statistics – therefore falling victim to overgeneralizations in the assessment. Secondly, and partly related to the lack of existing knowledge of the cost of deployment, there have been only limited attempts to identify the financing gap and accordingly, to put the claims for public support for deployment on a sound economic basis. Thirdly, despite wide existing research on the economic impact of telecommunications and the Internet, it remains to a large extent unclear what the particular benefit is for consumers of having super high-speed access at home through NGNs, that is: What is the added economic benefit of upgrading from basic broadband connections?

The purpose of this paper is to address these shortcomings. The paper is structured as illustrated in Figure 1. Firstly, the assessment of broadband infrastructures and development of NGNs in particular cannot be disconnected from the underlying technologies – that is: What are NGNs and how do they differ technologically from other network infrastructures? The answers to these questions, given in Section 2, are imperative as they drive technical alternatives, further impacting on the deployment cost and the assessment of financing gaps and economic returns. Then, an overview and discussion on the Digital Agenda targets are provided, as these targets are likely to provide the main policy

With the EU Digital Agenda as a benchmark, this paper assesses investment needs and the market shortfall in financing.

reference for NGN development in Europe in the coming years (Section 3). Once the vision set in the Digital Agenda has been clarified ("to-be" state), the current state of network infrastructures ("as-is" state) is assessed to identify the coverage gap (Section 4). Once the gap has been identified, a deployment cost assessment can be made, thereby identifying the financing needs (Section 5). This is followed by the assessment of market shortfall in financing such network deployments and the need for public intervention, also touching on issues such as customers' willingness to pay (Section 6). To assess the justification of public intervention, it needs to be assessed whether the economic benefits of NGNs actually outweigh the cost of deployment (Section 7). A discussion on potential mechanisms for public intervention is provided in Section 8. Finally, Section 9 offers a summary of the main results and some insights for policy makers.

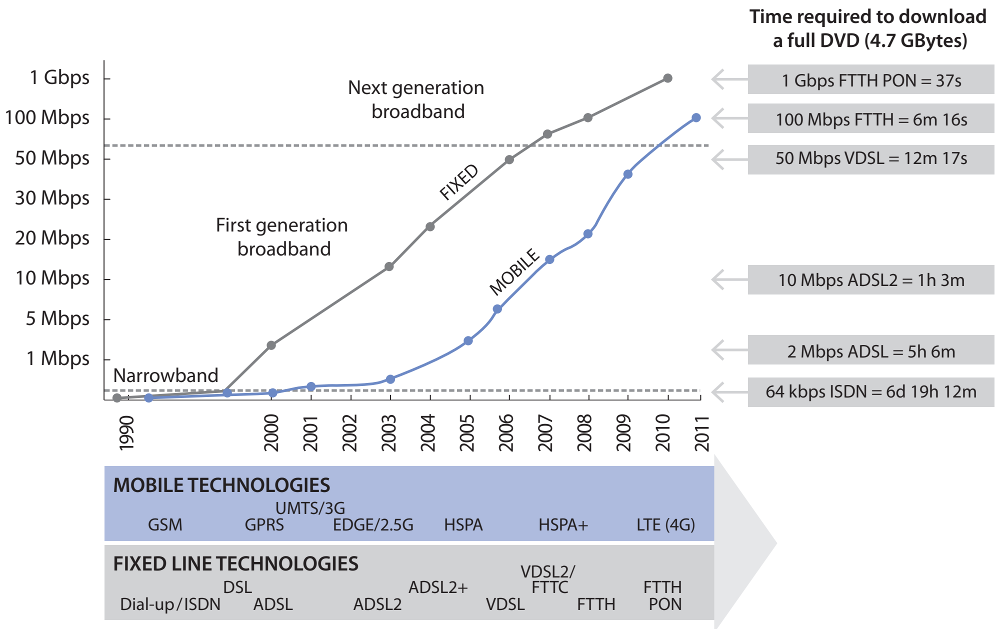
Figure 1. Structure of the paper and research questions



2. Network generations: What is the next generation in broadband networks?

The telecommunications standardization body of the International Telecommunications Union (ITU-T) defines next generation network as "a packet-based network able to provide services including telecommunication services and able to make use of multiple broadband, quality of service-enabled transport technologies and in which service-related functions are independent from underlying transport-related technologies. It offers unrestricted access by users to different service providers. It supports generalized mobility which will allow consistent and ubiquitous provision of services to users." This engineering-driven definition does not provide much to work with in assessing the economic aspects of these networks. In more general terms, NGNs refer to very high speed or super high speed broadband networks, often referring to fibre-based technologies in fixed line and 4th-generation networks in mobile. As opposed to basic broadband Internet connections, defined by the OECD in 2006 as having download data transfer rates equal to or faster than 256 kbit per second (kbps), with respect to NGNs, the discussion is often on access speeds beyond 50 Mbps – over 200 times the speed of basic broadband. Figure 2 provides a broad illustration of the evolution of access speeds and the corresponding evolution of fixed and mobile network technologies between 1990 and 2011.

Figure 2. The evolution of broadband access technologies and speeds between 1990 and 2011



Notes: Figure 2 is an illustrative description of the evolution of broadband access technologies and speeds. The access speeds refer to reported download speeds.

The term "next generation network" derives from the historical developments of broadband technologies. Both fixed and mobile technologies have evolved significantly since the late 1980s and early 90s, a time when the first dial-up (ISDN) Internet connection became available over telephone lines and the first GSM mobile networks were introduced. In the second half of the 1990s, digital subscriber line (DSL) technology was introduced, initially providing some 200 kbps access speeds but the importance was in paving the way for further development of the ADSL technology, which enabled access speeds from 2 Mbps (ADSL) all the way to 24 Mbps (ADSL2+) today. In the mobile arena, the first data networks (GPRS, UMTS and EDGE) deployed after the turn of the millennium provided access speeds up to 600 kbps. However, it was the HSPA technologies first introduced in 2005 that really enabled transfer of data in mobile networks. The first HSPA networks enabled data transfer speeds of 2 Mbps, but currently the evolutions of this technology allow theoretical speeds close to 50 Mbps. To put these access speeds into perspective, Figure 2 also illustrates the time required to download a full DVD movie from the Internet with certain fundamental access speeds. With an early 64 kbps ISDN connection, the download would have taken close to 7 days and with a 2 Mbps ADSL access still common among households, the download would take over 5 hours, but with an access allowing 100 Mbps (fibre or LTE), the download would only be a matter of a few minutes.

NGNs require massive investment in new infrastructure, be it in the fixed-line or in the mobile arena.

These technologies allowing super-high access speeds are often referred as next generation networks (NGNs). In fixed line broadband, DSL and its gradual developments (ADSL, ADSL2, and ADSL2+) are seen as the first-generation broadband, replacing narrowband dial-up Internet connections. Although significant efforts are still put into increasing the possible access speeds in the copper line network, the next generation often refers to fibre-based technologies, where the fibre is deployed to the curb (VDSL/FTTC), building (FTTB) or all the way to the customer (FTTH – fibre to the home). In the mobile arena, NGNs are often used to describe long-term evolution (LTE) networks, while the existing High Speed Packet Access (HSPA) technology and its evolutions, although considered as third-generation (3G) mobile technologies, are considered as the "first" generation broadband (Friedrich *et al.* 2009). What is common in both cases is that NGNs require new infrastructures to be deployed as opposed to upgrading the electronic components or software of existing infrastructures. Therefore, the deployment of such networks imposes a great financial stretch to the industry, as the upgrade to NGNs is completely different from prior upgrades of copper and cable infrastructures. Rather than swapping equipment at either end of an existing access network, fibre requires building an entirely new network, which inevitably makes the upgrade much more expensive. Thus, together with the high cost, the issue of the economic value added of NGNs is constantly discussed.

3. The Digital Agenda for Europe initiative

Through the presentation of the Europe 2020 Strategy[1], the European Commission acknowledged the economic and social benefits from a Digital Single Market based on fast and ultra-fast Internet and interoperable applications. In this communication the European Commission launched the Digital Agenda (DA) for Europe, one of the seven flagship initiatives introduced to foster smart, sustainable and inclusive growth in the EU. With respect to the development of broadband infrastructures in the EU, it stated three concrete targets:

- **Target 1**: to bring basic broadband access for all Europeans by 2013;
- **Target 2**: to enable access to much higher Internet speeds (30 Mbps or above) for all Europeans by 2020; and
- **Target 3**: to ensure that 50 percent or more of European households subscribe to Internet connections above 100 Mbps by 2020.

Investment needs depend on the interpretation of the EU targets relative to access speed, point of access and whether the targets refer to each and every member state.

To reach these ambitious targets, the existing broadband network infrastructure needs to be extended by a smart mix of wireless and wire-line technologies. However, these targets, as they are formulated, remain open to further interpretations. Firstly, what is the definition of "basic broadband" in Target 1? For instance, while OECD defines broadband as having access speeds of 256 kbps and above, and some instances define even lesser thresholds, in current times basic broadband commonly refers to access speeds above 1 or 2 Mbps. Secondly, what is actually meant by Targets 2 and 3? Are the threshold speeds simply download or do they entail upload as well (symmetric or asymmetric), and are speeds guaranteed/actual speeds, advertised, theoretical speeds? While certain technologies are good in providing very fast download speeds they suffer from technological constraints to provide similar upload speeds. Also, theoretical speeds are typically much bigger than advertised speeds, which again are higher than actual user experience. Thirdly, what is the definition regarding the level or point of access? Does the definition of "have access to" refer to the workplace, village, building passed, home passed, *etc.*? For instance, a home connected to the Internet is different from a home passed by the Internet, just like a home connected to the road network has a driveway and is thus different from a road passing the home. Finally, what is meant by 50 percent of European households in Target 3 – is it the pan-EU average or each of the 27 national averages? If the former is meant, for instance, Target 3 could be reached by only covering the biggest cities of Europe with super-fast broadband irrespective of their country.

The way the DA targets are interpreted affects the scale and the type of available technologies to be deployed, which, in turn, has huge implications for the total required investment. In the methodology to address the total cost of fulfilling the DA targets discussed in Section 5 below, the different interpretations are built into different scenarios to quantify the total cost of different possibilities.

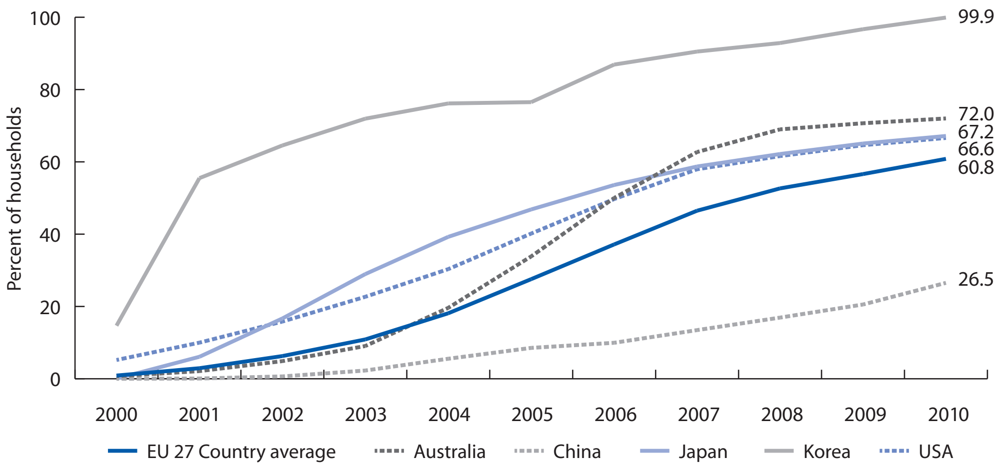
1 Europe 2020: a European strategy for smart, sustainable and inclusive growth.

4. The current broadband environment in Europe

To gain a better understanding of the magnitude of investment required to fulfil the DA targets, the current broadband environment in Europe needs to be looked at. At the end of 2010, the broadband household penetration (*i.e.* the share of households actually subscribing to broadband service) in EU countries reached 60.8 percent (simple average of national penetration rates) (Figure 3). This is below the penetration rates of other developed nations such as the US (66.6 percent), Australia (72.0 percent) and Japan (67.2 percent), and well below technology leaders such as Korea with 99.9 percent household broadband penetration. China is still lagging behind in this respect with only a 26.5 percent household broadband penetration, but it has shown accelerating growth in the past few years. At the end of 2010, the broadband penetration in EU-15 countries was 67.9 percent of households, while in the new member states, the penetration was 52.0 percent.

At 61 percent on average, EU countries had lower broadband household penetration than other developed nations in 2010.

Figure 3. Broadband household penetration in EU and comparison

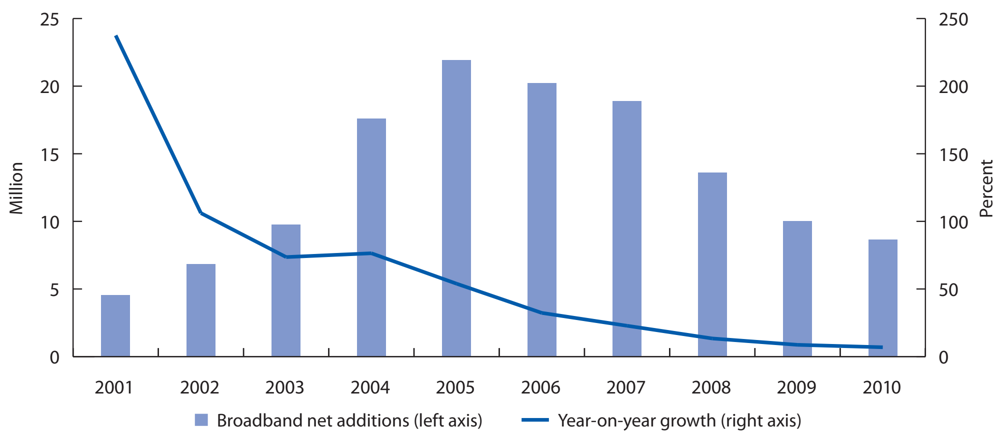


Source: World Broadband Information Service (WBIS)
Note: The WBIS does not provide a clear definition of broadband, but the latter can be seen as referring to Internet connections with access speeds above 150 kbps.

In respect of broadband technologies, xDSL (including all the different DSL evolutions discussed above) is the most used access medium, accounting for 64.4 percent of all broadband connections in the EU and connecting close to 40 percent of EU households to broadband Internet. Cable accounts for 21.2 percent of all broadband connections with a household penetration of 13 percent. FTTx technologies account for 8.7 percent of broadband connections and a household penetration of 5.6 percent. Other access domains (including powerline, fixed-wireless, WiMax and Ethernet UTP/FTP) account for 5.7 percent of connections, corresponding to household penetration of just over 3 percent. Accordingly, fibre-based NGNs currently account for less than 10 percent of all broadband connections.

The growth momentum of broadband penetration has been steadily declining in the past years, as is illustrated in Figure 4. For instance since 2005, representing the highest growth year in absolute net additions, the absolute net additions have dropped from 21.9 million to 8.7 million in 2010, and the relative growth dropped from 53.9 percent in 2005 to 6.9 percent in 2010. This illustrates early signs of market maturity. However, the household penetration rates above 80 percent in the Netherlands and Denmark for instance, and still continuing growth in these markets, indicate as an example that there is still room for improvement if demographic and technical challenges can be overcome.

Figure 4. Absolute and relative growth of broadband subscriptions in the EU

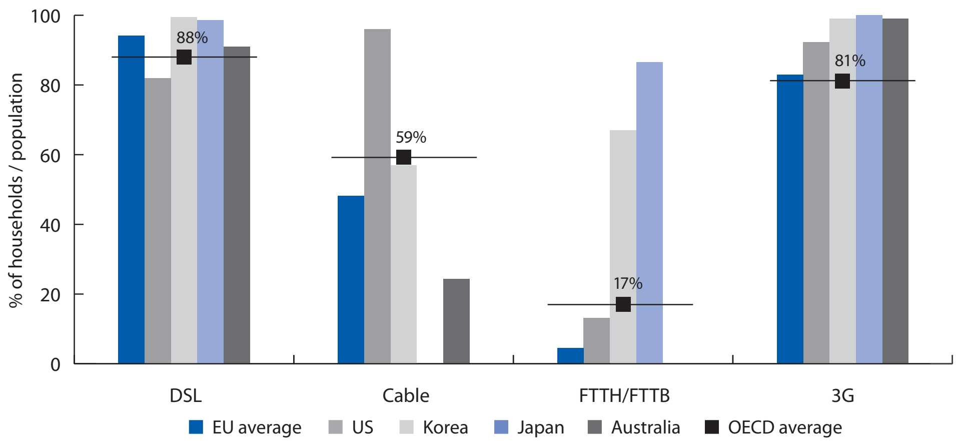


Source: WBIS

Coverage gaps are largest for the fastest broadband connections (cable and fibre to the curb/building/home).

While the penetration of broadband is the key determinant in generating economic return, in assessing the total cost of deployment, it is the total coverage of different broadband technologies that matters. Coverage reflects the availability of service, not uptake, and is therefore inherently greater than penetration. Apart from xDSL and 3G, Europe is lagging behind the OECD average regarding the coverage of different broadband access technologies (Figure 5). In particular, European countries are trailing other developed countries and technology leaders such as the US, Japan as well as Korea in coverage of access technologies allowing very high broadband access speeds, namely cable and FTTx technologies. For instance, while the OECD average for FTTx coverage is 17 percent, the EU average is only 4.5 percent. Similarly, at 48 percent, cable coverage, which can allow very fast broadband speeds, is below the OECD average.

Figure 5. Coverage of different broadband access technologies in selected countries

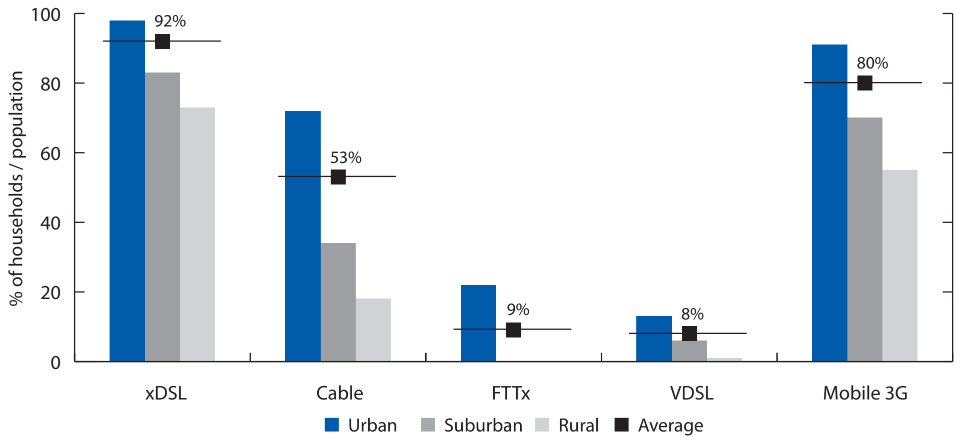


Source: OECD (2010)

Notes: EU in this figure refers to the 21 EU countries that are members of the OECD. The data are gathered from various sources by OECD and in some cases rely on different periods, causing certain issues of comparability with *e.g.* the WBIS data.

In the EU-27, the total broadband coverage with different technologies is as follows (averaged by country): xDSL 92 percent of all households, cable 53 percent, FTTx 9 percent, VDSL 8 percent, and mobile 3G 80 percent. The big challenge for broadband availability in the EU seems to lie in the more remote and particularly rural areas. For instance, as shown in Figure 6, xDSL coverage in urban areas is 98 percent of households, while the coverage is only 73 percent in rural areas. Moreover, with respect to cable, urban areas have coverage of 72 percent while rural areas have only 18 percent, and the existing FTTx deployments seem to have focused on the urban areas only, providing a total coverage of 22 percent of the European urban households.

Figure 6. Coverage of different broadband access technologies in the EU and demographic breakdown



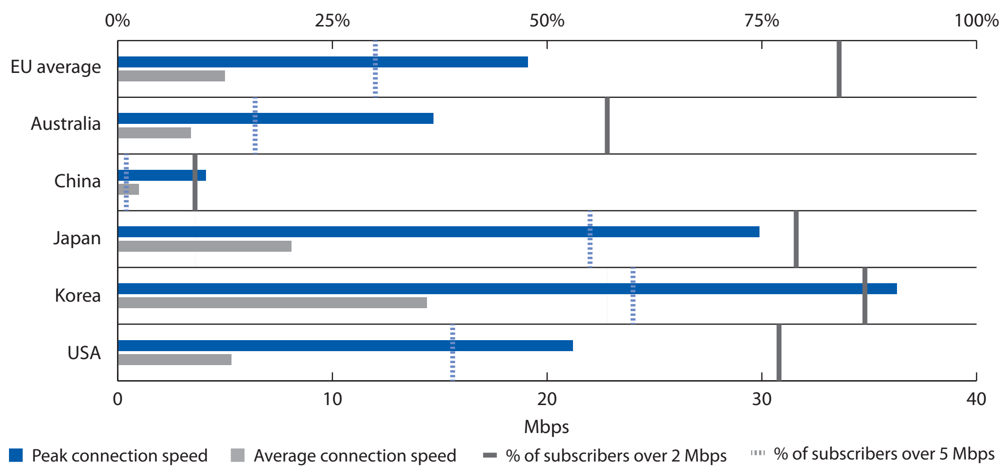
Source: iDATE; national statistics

Notes: Urban = more than 500 inhabitants per km²; Suburban = between 100 and 500 inhabitants per km²; Rural = less than 100 inhabitants per km². The minor discrepancies between the coverage data represented in Figures 5 and 6 are due to data source differences. Also, Figure 5 only includes European countries belonging to the OECD, while Figure 5 includes all EU-27 countries.

Average access speeds in the EU reflect a lack of high-speed network infrastructure.

The average broadband access speeds in the EU reflect a lack of high-speed network infrastructures. According to a recent study (Akamai 2011), the average connection speed for an average broadband subscriber in the EU is 5.0 Mbps, ranging between 3.5 and 7.5 Mbps between countries. In the US, the average speed is only slightly higher (5.3 Mbps), but in Japan (8.1 Mbps) and Korea (14.4 Mbps), average broadband speeds are significantly higher (Figure 7). In the EU, the average peak connection speed is 19.1 Mbps, ranging between 13.9 and 32.7 Mbps. Although this is somewhat irrelevant in respect of the actual user experience, it illustrates the access speed capabilities of the network. 84 percent of the broadband connections are above 2 Mbps, one of the highest shares in the world, whereas only 30 percent is above 5 Mbps. As a consequence, the EU is trailing behind other developed broadband markets such as the US, Japan and Korea in terms of connections faster than 5 Mbps.

Figure 7. Connection speeds in the EU and selected countries



Source: Akamai (2011)

It will be challenging to bring Europe to the level of other digitally developed nations in terms of very high-speed broadband.

Therefore, it seems it will be a huge challenge to bring the European broadband markets to the level of other digitally developed nations in respect of availability and use of very high speed broadband. In addition to the need of increasing the availability of basic broadband in rural areas to bridge the digital divide (Target 1 of the DA), the EU would have to catch up in the provision of network infrastructures allowing very high and super high-speed broadband in order to meet Targets 2 and 3 of the DA. However, increasing network coverage does not lead to a one-to-one increase in the uptake of the service, as there exists an inherent demand-supply gap in the provisioning of broadband services. For instance, while more than 90 percent of EU households have currently access to xDSL broadband, just over 60 percent of households are actually subscribing to the service (Figures 6 and 3). The demand-supply gap for super-fast broadband access is likely to be greater still, particularly due to low perceived value in addition to basic broadband and therefore lacking willingness to pay more for the service. This will be discussed further in Section 7.

5. The cost of reaching the Digital Agenda targets

Between July 2010 and March 2011, the European Investment Bank (EIB) commissioned a study with the aim to assess the cost associated with the DA broadband targets. While earlier attempts to quantify this focused on the investment needs to reach full European coverage with fibre-based networks (*e.g.* OECD 2009), often relying on pan-EU averages, the approach in this study is technology neutral, applying a mix of available technologies to meet the targets at different access speeds. The assessment in this study follows a bottom-up approach – building from country level assessments to an aggregate EU total.

5.1 Methodology

In order to maximise the flexibility of the approach, the DA targets in the study are interpreted in different ways, resulting ultimately in four different scenarios. While all of them fulfil the targets set out by the European Commission, the quality requirements vary extensively. The scenarios reflect the following underlying base assumptions: Coverage (not penetration) is the benchmark infrastructure variable; certain niche technologies are excluded (*e.g.* Satellite and WiMAX); the focus is on residential broadband access; competition is not considered, thus a single platform is modelled; and regulatory parameters are not accounted for. Specifically, for Target 1 it is defined that the basic broadband threshold is 1 Mbps, and for Target 3 it is assumed that a coverage of 50 percent of households needs to be achieved for each member country.

As regards the definition of deployment unit costs for each technology, industry benchmarks combined with EIB experience were used. Deployment unit costs for each technology were then adjusted with population density. For the purpose of the cost analysis, countries were split into urban (more than 500 inhabitants per km^2), suburban (between 100 and 500 inhabitants per km^2) and rural (less than 100 inhabitants per km^2) areas, since population density is the key determinant of deployment unit costs. This distribution was made based on the availability of coverage information of different broadband technologies. Ultimately, NUTS-4 level granularity[2] in population density and existing broadband coverage was applied. Further, different technologies were adjusted with a labour cost variable as the labour intensity of deployment varies across technologies. Several other variables affecting cost such as duct availability and terrain type were not included in the cost modelling due to a lack of EU-wide comparable data.

2 NUTS is the EU's Nomenclature of Territorial Units for Statistics. NUTS-4 (recently renamed into LAU-1) corresponds to local administrative units above the municipal level but much finer than the regional or county level.

The scenarios assume different speed requirements (theoretical/advertised, actual, symmetric) and access requirements (household access or communal access). These scenarios are shown below with an illustration of a set of technologies to be deployed to fulfil all the three targets:

The scenarios assume different speed and access requirements.

- **Minimum**: Theoretical download speed, with Internet centres in rural areas
- **Base**: Theoretical download speed, coverage of the household
- **Advanced**: Actual download speed, coverage of the household
- **Maximum**: Actual symmetric download and upload speed, coverage of the household

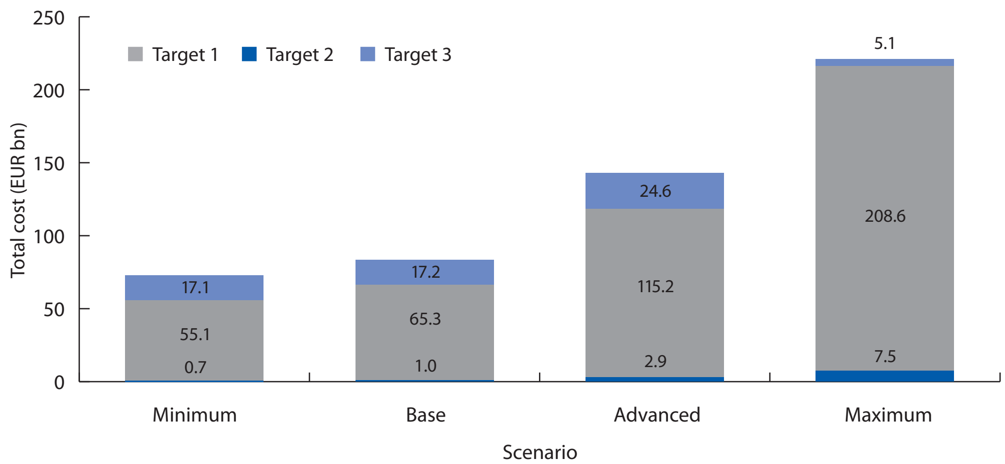
Every target in each scenario for each area leads to a range of available technological solutions, creating a three-dimensional framework for the cost analysis. The technology with the lowest unit cost to fulfil the requirements is applied. In addition, the application of cable infrastructure is analysed separately due to a lack of information on the quality of the existing cable infrastructure in Europe. This creates an additional fourth dimension to the analysis, which is not discussed in detail in this paper.

5.2 Results

Based on the methodology summarised above, the study finds that the total cost of implementing all three DA broadband targets varies between EUR 73 and EUR 221 billion. Fulfilling Target 1 requires between EUR 1 billion and EUR 7 billion. Fulfilling Target 2 requires between EUR 55 billion and EUR 209 billion, representing 76 percent to 94 percent of total cost, the proportion being higher in scenarios with higher quality requirements. Fulfilling Target 3 requires between EUR 5 and EUR 25 billion. The low amounts required for Target 3 are due to the cumulative deployment approach, whereby the target can be achieved basically by upgrading the infrastructure deployed for the purpose of Target 2. Total costs across scenarios and split by targets are presented in Figure 8.

If existing cable coverage were considered as fully broadband enabled and upgradeable technology, the total cost would decrease by roughly 30 percent in the minimum, base, and advanced scenarios. In the maximum scenario, there would be no difference, as high symmetric service quality requires fibre deployment.

Figure 8. The total cost of fulfilling the Digital Agenda broadband targets in different scenarios



While stricter interpretations of the EU broadband targets imply a much higher total cost and a larger cost share falling on rural areas…

When the total cost in each scenario is broken down by demographic areas (based on population density), the urban share of the total investment need decreases as scenarios become more ambitious, while the rural percentage increases. For instance, in the minimum scenario, total-cost shares are approximately 5 percent for rural, 47 percent for suburban and 48 percent for urban areas, respectively, whereas in the maximum scenario, rural areas account for 45 percent of the total cost, suburban areas for around 32 percent and urban areas for the remaining 23 percent.

When the total cost of the maximum scenario is further broken down by individual DA targets, the rural percentage of target cost decreases when moving from Target 1 towards Target 3 while the urban percentage increases. This is not surprising since in practice, Target 3 is primarily an urban initiative based on our cost assessment (51 percent of EU households live in urban areas). On average across scenarios, 25 percent of total investment is required to upgrade and deploy urban infrastructure (51 percent of EU households), 34 percent is required for suburban (30 percent of households) and 41 percent for rural infrastructure (19 percent of households).

Looking at results by country, Europe consists of a heterogeneous sample of leading broadband infrastructure countries such as Belgium, Latvia and Slovenia on the one hand and countries with less advanced infrastructures such as Cyprus, Greece and Poland on the other. The countries requiring most of the total investment are Germany (between EUR 14 and 43 billion), France (between EUR 9 and 31 billion) and the UK (between EUR 11 and 26 billion). It turns out that the five biggest countries in terms of population (France, Germany, Italy, Spain and the United Kingdom) require between 63 percent and 72 percent of the total cost, more than their share in total EU population (62 percent). Furthermore, while the EU-15 accounts for between 80 percent and 84 percent of total cost (in line with its share in total EU population), it is below 40 percent of the total cost of reaching Target 1 across scenarios except for the maximum scenario. Reaching Targets 2 and 3 in the EU-15 would require 81-83 percent of the total cost. Thus, also apparent in coverage statistics, although EU-15 is more advanced in enabling basic broadband, it is in fact not much ahead of the new member states in NGN infrastructures. This is partly due to technological leapfrogging, that is, the new member states are not bound to legacy copper lines but have switched directly to deploying fibre.

A map illustrating the estimated total country costs per target can be found in Appendix 1.

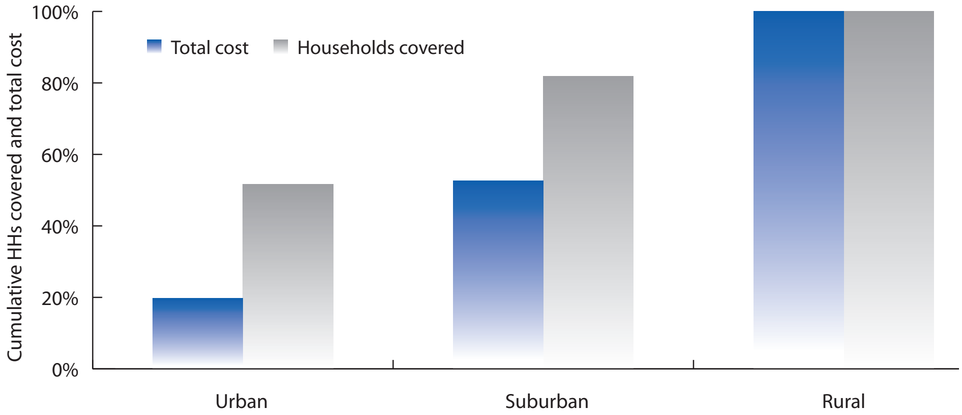
5.3 Implications of the cost assessment

Overall, the results translate into a yearly investment need of between EUR 5 and EUR 22 billion, which is significant given, for instance, that in 2008 the total capital expenditure in the electronic communication sector in the EU amounted to EUR 47 billion. Therefore, and regardless of the interpretation of the DA targets and the underlying technologies, the high investment costs combined with long payback periods involved with these infrastructures and the uncertain cashflow streams related to them affect market-driven investments. Moreover, total investment in the telecommunications industry is declining in the EU, not only due to the macroeconomic climate but mainly because of the declining revenue outlook in the industry. What is more, investment is declining at an even faster pace than the revenues. The intensity of investment as measured by the ratio of capital expenditure to revenues is declining but is estimated to remain around 11 percent (down from a level of 14 percent in 2008 and 15 percent in 2007). This will increase the amount of public support needed for the DA targets to be met.

95 percent of the total estimated cost falls on achieving the targets regarding the higher access speeds (Targets 2 and 3) that require deployment of NGNs. Although mostly beneficial from an overall economic point of view (see Section 7 below), such investment needs create a great financial stretch for the

industry, in particular because a substantial part of the investment is expected to have low financial return. The results of this study suggest that rural areas account for over 40 percent of the total investment requirement, although they occupy less than 20 percent of all European households. In fact, the higher the quality requirements, the higher the share of cost falling on rural areas. Figure 9 illustrates the cost distribution of full EU-wide FTTH deployment (totalling EUR 208.6 billion), which is based on maximum scenario Target 2.[3] Accordingly, to connect 51 percent of the EU population (those living in urban areas), only 20 percent of the total cost is required. To cover all households in urban and suburban areas (81 percent of EU population) only some 50 percent of the cost is required, while the rural areas with less than 20 percent of the population require the remaining 50 percent of the total cost.

Figure 9. Cumulative shares of total cost and households covered in full FTTH deployment scenario



Note: "Urban" refers to areas with more than 500 inhabitants per km², "Suburban" to areas with 100–500 inhabitants per km² and "Rural" to areas with less than 100 inhabitants per km².

…lax interpretations of quality requirements would not be useful.

Although from the perspective of fulfilling the DA targets it is tempting to assume lower quality requirements, this would not provide a useful base for further development. For instance, it is not worthwhile to discuss theoretical or advertised speeds of technologies, as they do not reflect reality. It would be like building a motorway where the theoretical speed is given by the physical limits of the vehicle, but in reality traffic and speed limits imply a much lower actual speed. Also, as will be discussed further in Section 7, the benefits of NGNs increasingly derive from services relying not only on super-high download speeds, but also on similarly high upload speeds. Our "Maximum" scenario is the only one to cater to this important development. With these assumptions, and to simplify further analysis and reporting, the following sections focus on full EU-wide FTTH deployment – although the methodology could be applied to any other technology.

6. Assessing the financing gap in the deployment of NGNs

The key question in addressing the level of public intervention required to reach the DA targets is to assess the level of financing gap, in our case defined as the difference between the investment cost of full EU-wide FTTH deployment and the sum of funds likely to be provided by the private sector to finance that investment.

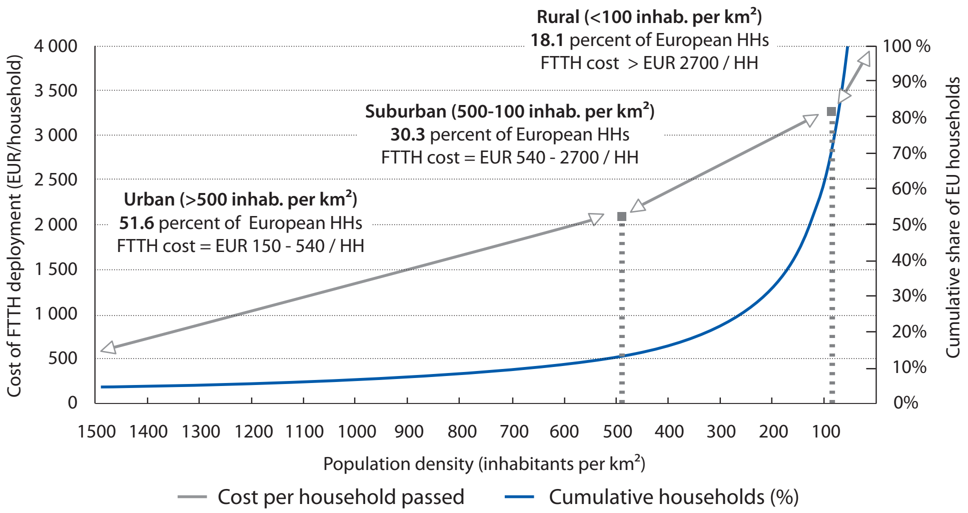
3 In the maximum scenario, the requirement to meet Target 2 is to deploy infrastructure allowing 30 Mbps actual symmetric speed. Only FTTH technology is able to provide that.

To assess the financing gap, NGN deployment costs are compared with the capex threshold (i.e. the maximum capital expenditure that can be funded by revenues).

The methodology used to examine the financing gap consists in finding so-called capital expenditure (capex) thresholds for market operators to provide a business case for fibre deployment. The capex threshold is the maximum capital expenditure that can be funded by expected revenues, that is, the investment volume up to which FTTH deployment is financially viable. Finding the capex thresholds first requires developing a cost curve as a function of population density, which can be represented in a cumulative manner, going from high-density (*i.e.* low-cost) areas to low-density (high-cost) areas. This representation allows stating that, for instance, 40 percent of EU households live in areas where FTTH deployment costs less than EUR 500 per HH. Next, hypothetical business cases are built using multiple scenarios, variables, and sensitivities, from which the capex thresholds are derived. These capex thresholds can then be translated into population densities, and further to the share of total required cost based on the results of the cost study. The difference between the capex threshold and the total cost of deploying an EU-wide FTTH network gives an indication of the financing gap.

The reported costs for a household passed with fibre (FTTH) vary greatly with population density. The cost is of course dependent on several other variables such as availability of ducts, type of terrain and local labour costs. EIB experience and industry benchmarks were used to identify the cost distribution curve in different population density areas. The identified cost points were further connected by applying a relatively simple methodology[4] given limited data availability. By applying this approach, we arrive at cost levels between EUR 150 and EUR 540 per home passed in urban areas, between EUR 540 and EUR 2700 in suburban areas, and over EUR 2,700 in rural areas (Figure 10). For each home passed, there is a fixed-cost element irrespective of population density. It is estimated at EUR 150 per home passed and represents the lowest possible cost level.

Figure 10. Cost of fibre deployment per household and population density in the EU



From these cost estimates, it is now possible to derive the capex thresholds for market operators to invest in fixed infrastructure, assuming – as is typically done – a 10 percent discount rate (weighted average cost of capital – WACC) and a 10-year payback time. To obtain the capex threshold per home

4 A benchmark value for deployment cost of EUR 112,500 per km² is derived based on various sources of industry benchmarks and EIB experience on costs per household covered in different areas with varying population density. This translates into an average cost per household passed at different population densities (assuming 2.4 inhabitants per household on average based on Eurostat). For the purpose of this analysis it is assumed that the household size is the same in different density areas. While this is a simplification, it gives a sufficient base for assessing the finance gap. Also, due to the fact that the deployment cost is dependent on a number of cost variables, with no data available for several of them, an accurate computation would be impossible to achieve anyway.

passed, a hypothetical business model is built for three different ownership scenarios: Single proprietary network deployment; single open-access network deployment; and single network co-build by three market operators (Table 1). The deployment of a proprietary network allows the service provider to collect relatively high average revenue per user (ARPU)[5] and to achieve a relatively high service uptake due to lack of competition. The deployment of an open-access network in turn allows wholesale offerings (*i.e.* leasing of the network capacity to other operators), which is, however, expected to slightly lower the uptake of direct retail service. The co-building scenario allows shared capex, but is likely to result in lower ARPU and uptake for the individual service provider due to increased competition. For each of the scenarios, a low and high variant is built based on service uptake.[6] The assumptions underlying the EBITDA margins (retail, wholesale and "co-build") are based on industry benchmarks.[7]

To push up the capex threshold, an operator may aim for wholesale revenues (opening the network to rivals) or for lower costs through collaborative roll-out and co-ownership.

Table 1. Scenarios and variables for assessing market thresholds for NGN deployment

Type of deployment	Variables	Sensitivity variables	Capex threshold
Single proprietary network deployment	Retail ARPU EUR 50 per month and EBITDA 40 percent of revenues	High scenario uptake 40 percent and low scenario uptake 25 percent	EUR 648 / HH in high scenario and EUR 405 / HH in low scenario
Single open-access network deployment	Retail ARPU EUR 50 and wholesale ARPU EUR 15 per month; retail EBITDA 40 percent and wholesale 80 percent of revenues	High scenario retail uptake 30 percent and wholesale 20 percent, and low scenario retail uptake 20 percent and wholesale 10 percent.	EUR 681 / HH in high scenario and EUR 421 / HH in low scenario
Single network co-build by three operators	Retail ARPU EUR 40 per month and EBITDA 60 percent of the revenues	High scenario uptake 20 percent per service provider (i.e. 60 percent total) and low scenario uptake 10 percent per service provider	EUR 1,160 / HH in high scenario and EUR 584 / HH in low scenario

Notes: ARPU = average revenue per user; EBITDA = earnings before interest, tax, depreciation and amortization; HH = household. Certain factors which may shift market operators' willingness to invest not included. For example, upsides not included in the model are market share protection for converged operators, and the fact that there is no upfront connection fee assumed. A downside not included is that all the models do not take into account areas with existing own or competing networks (ADSL2+ or cable).

With these assumptions and baseline variables, it seems that the capex threshold for deploying a commercially viable single proprietary network is in range between EUR 400 and EUR 650 per home passed, between EUR 420 and EUR 680 for a single open-access network deployment, and between EUR 580 and EUR 1,160 for single network co-build.

5 The ARPU of EUR 50 is based on Broadband Internet Access Cost (BIAC 2009) report on a dual-play offering (Internet +20 Mbps and TV). The EU-27 average for such service was EUR 52 in 2009. A dual-play offering is selected as the baseline here although a triple-play offering including fixed telephone service would provide a premium of EUR 10. On the other hand, some customers may opt for a single Internet service with an average cost of EUR 40.

6 It is also assumed that the implementation is in areas with no existing network for the deploying operator. If there was an existing DSL network, for instance, this would significantly degrade the capex threshold and hence, the willingness to invest, as revenue calculations would additionally have to take into account the loss of revenues from the existing DSL service. Especially for incumbent fixed-line operators with wide existing DSL networks, this is a key factor hindering their willingness to invest into FTTH infrastructures.

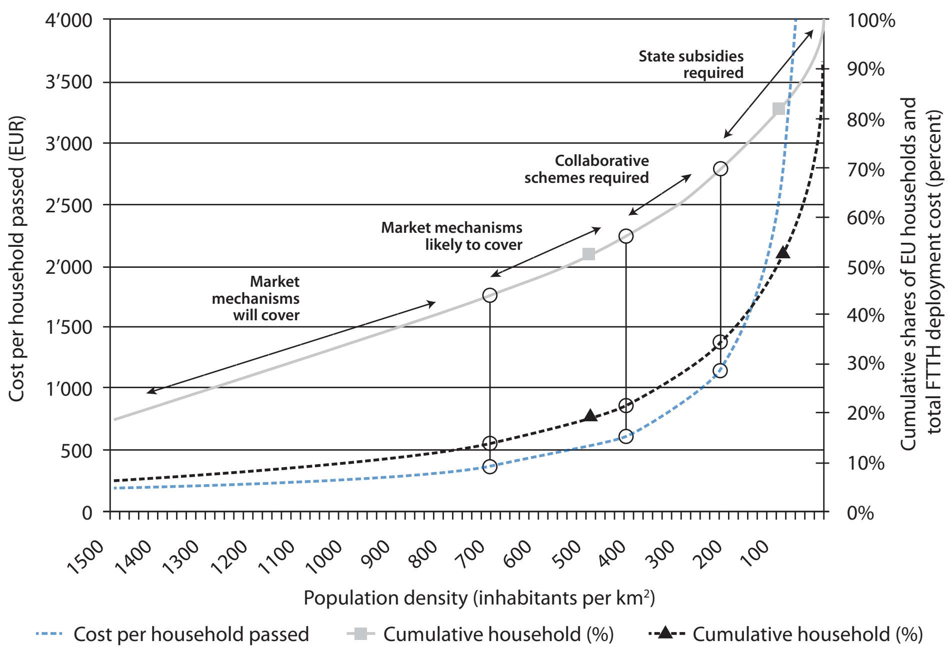
7 It is acknowledged that there is a positive correlation between the EBITDA margin and uptake of the service due to economies of scale. However, for the purposes of our assessment, average margins are used based on industry benchmarks in order to avoid making the assessment overly complex.

Figure 11 illustrates the capex thresholds with the unit cost curve combined with coverage of cumulative households. Based on the results, the following areas can be identified:

- Areas with full financial viability: Each deployment scenario is expected to yield positive returns for deployment cost less than EUR 405 per home passed. According to the cost curve, this corresponds to areas with more than 670 inhabitants per km^2. Deployment up to this low capex threshold would cover 45 percent of the EU-27 population, while representing only some 15 percent of the total estimated cost of deploying an EU-wide FTTH network.
- Areas with high likelihood for financial viability: Network deployments of a single operator may enjoy financial viability up to a unit cost of EUR 680 per household passed. This would cover areas with population density of more than 400 inhabitants per km^2 and represent some 55 percent of the EU population. This still represents only 21 percent of the total investment need.
- Areas in which financial viability can be attained through collaborative deployment schemes: Through co-deployment schemes, financial viability can be achieved up to a unit cost of EUR 1,160 per HH passed, corresponding to a population density of more than 220 inhabitants per km^2. This translates into an estimated 70 percent of the EU population, but only some 35 percent of the total cost.
- Areas in which state subsidies are required: In the remaining areas with population density below 220 inhabitants per km^2, it seems that direct public financial support (*e.g.* grants) is required to make the FTTH deployment viable. As Figure 11 shows, 65 percent of the total cost is required to cover the "last" 30 percent of the EU 27 population (61.5 million households).

While market mechanisms together with collaborative schemes would shoulder 35 percent of the cost, covering 70 percent of EU households…

Figure 11. The estimated financing gap in FTTH deployments



While the financing gap assessment above is based on a bottom-up approach, it is also relevant to assess the top-down approach. Indeed, the market cap for investments in the FTTH deployments depends on how much the market can afford to invest. In this respect, the total telecommunications market revenues were EUR 341 billion in 2008, with total capital expenditure of EUR 47 billion, corresponding to an investment intensity of some 14 percent (capex/revenues). Of the total investment, 70 percent is for fixed line (EUR 33bn) and 30 percent for mobile (EUR 14bn), although especially for converged operators this distinction is difficult to make. Furthermore, of the total investment in fixed line, only a limited share goes to new network deployment, while the majority goes to upgrading and maintenance of existing infrastructures, and also to data centres, buildings, capitalized R&D costs *etc*. It is estimated that roughly 20 percent to 30 percent of the total fixed line capex is directed to new network deployment, translating into a total amount of EUR 6.5 to EUR 10 billion. Over a 10-year horizon, based on the DA target for 2020, this would result in aggregate investment in new network infrastructures between EUR 65 billion and EUR 100 billion, which would correspond to 31-48 percent of the total estimated FTTH deployment cost and would translate into coverage of 67-80 percent. As a consequence, the top-down assessment is broadly consistent with the bottom-up analysis provided above.

However, due to market imperfections, these coverage figures are unlikely to be achieved through market mechanisms. Firstly, due to competition and the general aim of profit maximization, parallel deployments are likely to occur in the most profitable areas such as large cities and other densely populated areas. Secondly, currently 70 percent of fixed-line investment is done by incumbents. Incumbents with existing nation-wide xDSL connections are unlikely to deploy FTTH networks and to migrate customers to them, as the additional ARPU from having a super-fast broadband instead of fast broadband (xDSL based on copper) is currently limited.

Changing any of the underlying assumptions could change the results of the analysis significantly, because the identified capex thresholds and finance gaps are dependent on several variables and assumptions. Still, it provides an interesting illustration of the potential financing gap in reaching the DA targets regarding NGNs. In respect of using technologies (*e.g*. FTTB or FTTC) requiring lower capex per household covered, the variables throughout the assessment would change. For instance, while the capex is lower, the lower quality would definitely lead to lower ARPU and uptake rates due to lower added value and therefore willingness to pay. In fact, the key aspect behind the financing gap exercise is the added (perceived) value of NGNs and therefore the willingness to pay – further determining the ARPU and uptake rate which are the key variables in the financial viability assessment. The issue of added value of NGNs is further discussed in the following section.

Nevertheless, it is quite apparent that in reaching the DA targets especially with respect to NGN deployment, market mechanisms alone are unable to deliver the envisaged large coverage. Public support is required to reach the targets in full. However, the rationale for public support is contingent on the positive economic return of these networks, *i.e.* on a positive net benefit from society's perspective. The issue of economic returns to broadband and NGNs is discussed in the following section.

…the remaining coverage requires public support, which should be carefully assessed against net social benefits from NGNs.

7. Socio-economic benefits of broadband and NGNs

There exists a vast literature on the socio-economic benefits of telecommunications, Internet and broadband. For instance, in 2010, in the context of the UK Government digital inclusion work, Tech4i2 assessed the existing literature on economic benefits of Internet and found a total of 365 studies and research papers on the area. 41 percent of the studies examine the impact in the context of the US, while only 17 percent focus on Europe. A similar exercise was conducted by World Summit on the Information Society (WSIS), which summarizes 186 studies on the economic impact of broadband infrastructure and services. The key socio-economic benefits of the Internet outlined by the existing research are: increased economic growth and productivity, increased employment, improved healthcare and education systems, a positive impact on the environment, improved social inclusion, improved safety, improvement of well-being, and so on. This section first discusses the impact of Internet and broadband on economic growth and employment, followed by a discussion of the wider socio-economic benefits of basic Internet and broadband. In the final sub-section (7.3), the potential socio-economic benefits specific to super-fast broadband (NGN) are discussed.

7.1 Impact on economic growth and employment

Within the telecommunications domain, the main area on which the existing research has focused is the Internet's impact on employment and output, often stressing the Internet's positive effect on productivity growth and further on GDP growth. Stemming from the early study by Röller and Waverman (2001) who conclude that one third of growth in OECD countries between 1971 and 1990 can be attributed directly or indirectly to telecommunications, researchers have increasingly looked at identifying the growth effect of telecommunications, and later, of Internet and broadband in particular. Such studies account for 36 percent of all the studies identified by Tech4i2. This is due to the fact that these benefits are quantifiable, unlike the broader social benefits of the Internet.

A relatively unified consensus has evolved on the positive effect of broadband on economic growth and employment. Czernich *et al.* (2009), for instance, conclude that a 10 percentage point increase in broadband penetration raises annual per-capita growth by 0.9-1.5 percentage points. Similarly, Qiang and Rossotto (2009) find that a 10 percent increase in basic broadband penetration lifted GDP growth by an additional 1.12 percentage point in high-income countries. On productivity growth, LeCG find in their study that one more broadband line per 100 inhabitants (1 percent increase) in medium or high ICT countries increases productivity by 0.1 percent (LeCG 2009). Similarly, Friedrich *et al.* (2009) conclude that a 10 percent higher broadband penetration in a specific year is associated with a 1.5 percentage point greater labour productivity growth rate over the following five years. In sum, despite slight differences in the way the Internet's impact on productivity growth and GDP is measured and the variables used, prior research is relatively consistent in that every 10 percent increase in broadband penetration results in 0.9 to 1.5 percentage point higher GDP growth.

Marginal returns to broadband are large and have increased over time as the usefulness of communication networks increases with the number of users.

One interesting aspect of the telecommunications industry is that there exist increasing economic returns to scale and time. It is quite evident that in low-penetration countries, the lack of usage of broadband as an information and communications channel lowers the economic impact unless some critical mass is achieved. According to Koutroumpis (2009), the critical-mass effect can be achieved when 50 percent of the population in a given country has access to a broadband connection. As achieving the critical mass takes time – inevitably – time is an important factor in the analysis of economic benefits. Rausas *et al.* (2011), for instance, conclude that as markets mature, the contribution of the Internet to GDP growth increases: for example, in France the contribution is found to be 10 percent for the full observation period (1995-2009) but 18 percent in the later period (2004-2009). Across the range of mature countries they consider, the Internet contributed 21 percent to GDP growth, so for economies growing at 5 percent per annum, the impact of the Internet would be around 1 percent.[8]

Overall, Internet's and broadband's impact on GDP growth and productivity can be further broken down to different components, namely (i) employment generation, (ii) improvement in market efficiencies and consumer surplus, and (iii) improvement in productivity and operational efficiencies.

Firstly, in respect of employment generation, there have been arguments that the Internet has a negative or neutral impact on employment (*e.g.* Kenny and Kenny 2011). However, a detailed analysis

8 While this study focuses on the contribution of the Internet, it seems reasonable to assume that this is closely related to broadband, which has been the key driver of the mass market take-up of Internet-delivered services in the last decade.

of France over the past 15 years shows that, although the Internet has destroyed half a million jobs, it has created 1.2 million new ones translating into 2.4 new jobs for every one destroyed (Rausas *et al.* 2011). Further Fornefeld *et al.* (2010) find that the impact of broadband on companies resulted in a net creation of 105,000 jobs in the EU-27 in 2006, and broadband-related net job creation is estimated at more than 2m jobs between 2006 and 2015. In the context of the UK, Liebenau *et al.* (2009) find that an additional GBP 5 billion investment in broadband networks would create, and retain, an estimated 280,500 jobs in the UK. On a more general level, Crandall *et al.* (2007) report that for every 1 percent increase in broadband penetration, employment is projected to increase by 0.2 to 0.3 percent. In a historical assessment, Qiang and Rossotto (2009) find that broadband added 10-14 percent to the growth rate in the number of jobs between 1998 and 2002.

Studies on the GDP impact of broadband distinguish between employment generation; improving market efficiency and consumer surplus; and effects on productivity.

Overall, the impact of broadband for employment is three-fold. For one thing, the deployment of broadband infrastructures directly creates employment, however often restricted to the short term. Secondly, once the infrastructure is deployed, direct employment is created in the operation of the network. Thirdly, telecommunications generate employment in adopting and supporting industries. Studies have found that for every job the industry itself creates, two others are created in support services catering to the industry, and one more is created through the taxes collected from the increased revenues. However, from an economic perspective, the counter-argument remains for some of the above studies that a net increase in sectoral employment does not necessarily result in aggregate employment or welfare gains as the jobs created may be lost elsewhere or drive up wages.

For another, the growth effect of broadband derives from improving market efficiencies and consumer surplus. Market efficiencies translate into improved communication between the seller and potential buyers. However, in some cases the improvement of market efficiencies may result in a negative impact on GDP for an individual country by shifting the trade balance. For instance, while for several countries with low-cost manufacturing capabilities such as India and China, the increase in exports is a key economic benefit of the Internet, for some developed countries such as France, the UK and Italy, the Internet has increased imports more than exports (Rausas *et al.* 2011). Broadband has also been found to have the positive impact of attracting FDI inflow to the country.

Consumer surplus derives from consumers' ability to save money by being able to compare prices and order products online irrespective of the country of origin of the seller. In fact, private consumption via Internet currently accounts for 1.8 percent of mature countries' total GDP (Rausas *et al.* 2011). To the extent that this only reflects redistribution of consumer expenditures, it does not boost economic growth, but there are economic benefits from broadband. A clear indication of consumer surplus in broadband is consumers' willingness to pay for upgrade from dial-up (see *e.g.* Savage and Waldman 2004). A study by Rosston *et al.* (2010) finds that the average US household would be willing to pay about USD 45 per month to move from "slow" to "fast" broadband, indicating that fast broadband access generates value for consumers. On average, the estimated surplus value per Internet user in developed nations is between EUR 13 and EUR 20 per user per month (Rausas *et al.* 2011). However, what facilitates growth is competition within the sector leading to lower consumer prices (see *e.g.* Greenstein and McDevitt 2011). Therefore, network deployments which increase competition are likely to result in consumer surplus and hence, carry a growth impact.

Further, as to improvements in productivity and operational efficiencies, several studies have outlined that Internet leads to operational efficiencies and therefore productivity gains through more efficient supply, rationalization and digitalization of operations, and use of Internet as an important and low-cost sales and marketing channel. A study estimates that in France, Germany and the UK, businesses adopting Internet business solutions had accumulated additional revenues of EUR 86.4 billion and achieved cost savings of EUR 9 billion already by 2001 (Varian *et al.* 2002). Grimes *et al.* (2009) study the impact of slow and faster broadband access on firm productivity and find that firms with broadband connectivity had ten percent higher labour productivity than similar firms without broadband connectivity. Rausas *et al.* (2009) find that SMEs using Web technologies extensively are growing more quickly and are exporting more widely. There also exists a positive correlation between broadband penetration and innovativeness at the country level.[9]

7.2 Wider social benefits of broadband

Social benefits from the Internet include improved education and healthcare and positive effects on the environment.

In addition to the widely reported economic benefits, it is generally acknowledged that telecommunications and the Internet create a wide range of social benefits such as improved education and healthcare systems, better social inclusion, enhanced regional development, positive effects on the environment, improved safety, and a positive contribution to democracy and freedom of speech. Some of the key socio-economic benefits are discussed in more detail below.

In respect of the environment, although the telecommunications sector accounts for approximately 2 percent of global CO2 emissions, it accounts for close to 4 percent of global GDP. Furthermore, it is widely argued that broadband connections reduce the requirement to travel, both for business and in private, and therefore result in significant savings in CO2 emissions. The positive impact of telecommunications and ICT in general is the highest in the adopting industries. For instance, the SMART 2020 report finds that Information and Communications Technologies (ICT) could deliver 7.8 Gt of CO2 equivalents of emission savings in 2020, or 15 percent of global emissions in 2020, through applying smart solutions in automotive industries, logistics, construction and electricity. The application of intelligent ICT systems in motors, electricity grids, transport systems and buildings is expected to provide significant positive impacts on the environment. However, are these benefits related to broadband or ICT in general? Some argue (*e.g.* Kenny and Kenny 2011) that in fact the data transferred in solutions such as the smart electricity grids are so small, that they do not really require broadband connectivity – while others argue that smart grids are a benefit from super-fast networks (Ezell *et al.* 2009). Nevertheless, it is safe to assume that broadband enables several ICT based solutions applied in various industries, as well as enabling travel reduction, with high positive impacts on the environment.

Secondly, there has been a wide research on the impact of broadband in education and healthcare. In the area of healthcare, for instance, broadband networks enable distant monitoring and treatment, particularly of elderly people or people with chronic illnesses, leading to economic benefits through reduction in hospital admissions, emergency room visits and related transportation (see *e.g.* Enck and Reynolds 2009; CTC Report 2009). In the area of education, broadband enables, for instance, e-learning especially in rural and more remote areas, thereby also contributing to regional development. Virtual classrooms are set up where the distance between the pupils and the teacher has become irrelevant. Broadband access speeds are required to transfer video, sound and data between the student and the teacher.

While the benefits deriving from the environment, healthcare and education can be quantified to a certain extent, other social benefits of broadband such as the contribution to democracy and freedom of speech, increased social inclusion remain qualitative by nature. While these benefits are apparent also in developed nations, the key benefits in this respect occur in emerging economies.

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9 Among the EU-27 countries, a positive correlation exists between broadband penetration in 2009 and the related Innovativeness score of the country taken from European Innovation Scoreboard 2009 (InnoMetrics). The correlation coefficient is 0.40.

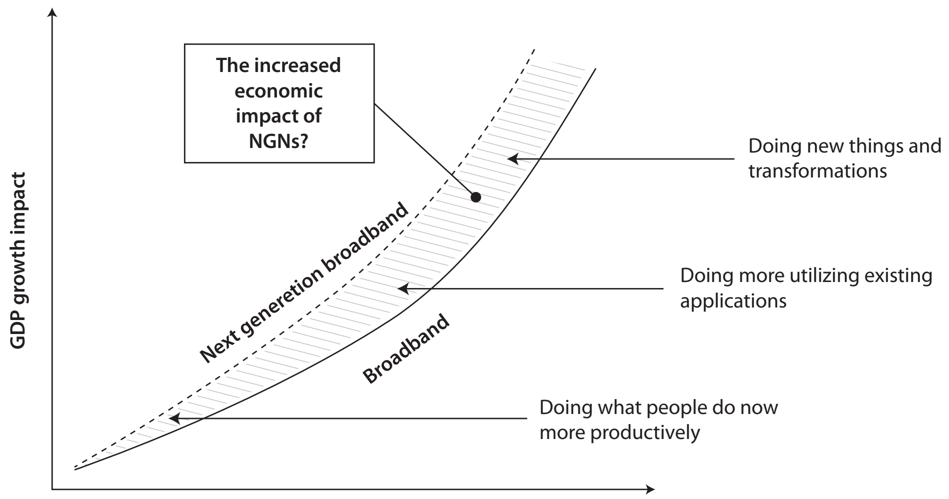
7.3 Socio-economic benefits of NGNs

In spite of the extensive research on the socio-economic impact of Internet and broadband, there is practically no existing research on the socio-economic benefits of super-fast broadband. Comparative assessments have been made in the past to address the added benefits from transferring from dial-up connections to broadband connectivity. However, the transition from basic broadband to next generation networks is more complex as it involves deploying entirely new network infrastructures, implying a great cost to the industry. From a policy perspective, when it comes to public support for the deployment of these networks, the key question is: Do the benefits of NGNs outweigh the cost of deploying these networks? And related to this, Kenny and Kenny (2011) rightly ask: "Is it really worth a subsidy?"

The benefits of super-fast over basic broadband concern time savings; 'doing more utilizing existing applications'; and unknown future transformations.

The complexity of this issue stems from the fact that, while it is relatively simple to address the impact of the Internet using no connectivity as a business-as-usual scenario, the assessment of NGNs needs to be done in comparison to existing basic broadband, which is available for almost the entire population of the EU. However, some initial attempts have been made to address this problem. In their assessment for the Broadband Stakeholder Group, Plum Consulting (2008) developed a framework for evaluating the value of next generation broadband. They consider three categories of benefits deriving from the replacement of existing copper networks with super high-speed fibre networks: (i) doing what people do now more productively (the value of time savings); (ii) doing more utilizing existing applications; and (iii) doing new things and transformations (Figure 12).

Figure 12. The socio-economic benefits of NGNs



First, in respect of "doing what people do now more productively", one approach would be to assess the time savings that can be achieved through NGNs. For the economic assessment of building new roads, for instance, time saving is one of the most commonly used variables in calculating the economic return. Similarly, it can be argued, in respect of broadband networks, that faster connections lead to time savings that can be monetized as an economic benefit. For instance, if we consider that out of the total EU-27 population of 492 million, 67 percent are of working age and the average value of time is EUR 10 per hour[10], only a one-minute daily saving per person resulting from the increased speed of the

10 Average based on different values of time for business, commuting / private time and leisure / holiday provided by van Essen *et al.* (2004). Although the valuations are built for assessing transport projects, the value of time should not differ.

network would result in an economic value of time savings of around EUR 20 billion a year. For example, one minute of time saved corresponds to the downloading of 40 Mbytes a day[11] with a 100 Mbps fibre connection, as compared to a 5 Mbps (ADSL) connection (currently the average). Although this calculation is illustrative only and neglects obvious counterarguments (*e.g.* increased speeds actually increase the frequency of use of the service), it underscores the economic potential of super-fast networks.

The value of time can also be assessed from a corporate perspective, whereby the basic hypothesis would claim that faster networks lead to operational efficiency gains. As a practical example, hospitals are increasingly moving towards IP standards whereby x-rays, medical samples *etc.* can be stored and shared in a digital format. This, however, requires significant download and upload access speeds as single images can be the size of two DVDs at the moment (8-9 Gbytes), and with the increase in accuracy of imaging and displays, the size is bound to increase. Using a VDSL2 connection, uploading a single image would load the network for over 2 hours, and accessing it would also require 25 minutes. With a symmetric 100 Mbps connection, both uploading and downloading would take an estimated 12 minutes, and with a 1 Gbps connection these actions altogether would require just over a minute. Therefore, common sense suggests that with faster connections, doing the same thing consumes less time and, hence, a certain level of economic benefits can be derived from NGNs.[12]

A number of services (e.g. videoconferencing and e-health) are only available via NGNs as they require high upload as well as high download speeds.

Second, as far as "doing more utilizing existing applications" is concerned, the key focus lies in assessing which applications are only available through NGNs. In the case of NGNs and fibre-based networks, it is generally argued that these networks will allow the roll-out of high-value applications which cannot be delivered in any other way, suggesting that additional bandwidth carries considerable returns. Several studies have emphasized a number of benefits to electricity, health, education, transportation and other public services from fibre networks (*e.g.* Enck and Reynolds 2009; Ecobilan 2008; Ezell *et al.* 2009; Ovum 2009). However, Kenny and Kenny (2011) argue that there are in fact only few applications that rely on super-fast broadband connections, and the majority of the applications that generate economic value added can be provisioned through existing infrastructures. This calls for further service-based assessment of the problem.

As can be seen from Figure 13, the services such as browsing and social networking are easily accessible with basic broadband connections. Advanced TV services require very high speed download connectivity. The services which need faster speeds and eventually next generation fibre infrastructures include multi-location collaboration (videoconferencing), cloud computing services and specific industry-specific applications (*e.g.* e-health) – all involving two-way traffic and therefore imposing high requirements both on upload and download speeds.

However, the question is: Is there any economic value-added from these services? Cloud computing is one widely cited example of services enabled by NGNs with high returns to the economy. In 2005, there were about 20 million SMEs in the EU-27 area creating an annual value-added of EUR 3,090 billion (source: Eurostat). A typical SME, according to Gartner estimates, spends around 5-7 percent of its revenues on IT, of which an estimated 50 percent is targeted to IT infrastructure maintenance. This translates into an annual SME IT spending of EUR 154 to 216 billion, with EUR 77-108 billion devoted to IT infrastructure maintenance. With cloud computing cutting spending on IT infrastructure maintenance

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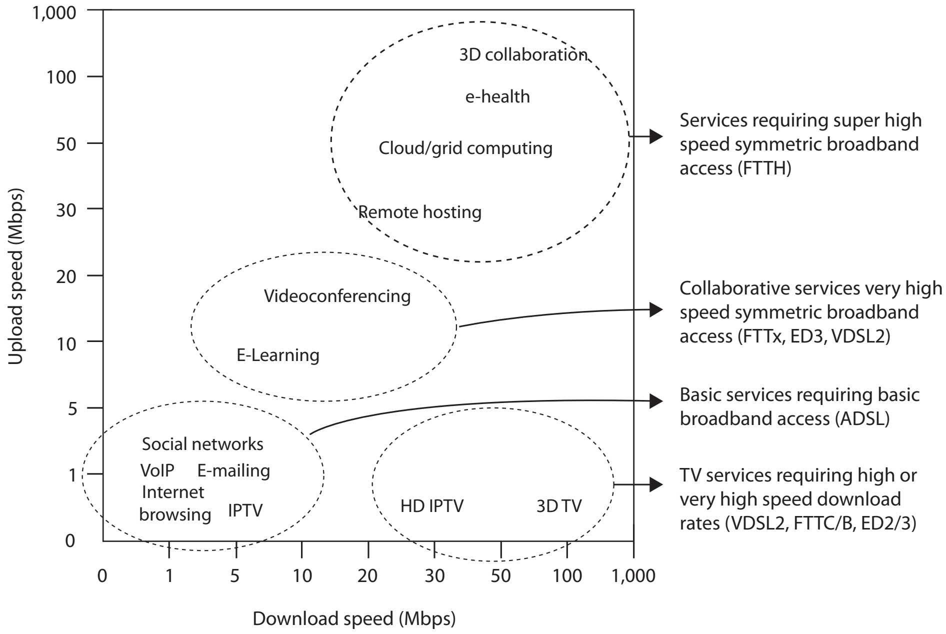
11 The 40 Mbps is a very conservative assumption as a recent study by Sandvine (2011) reported that the median usage of a fixed-line user is around 500 Mbytes a day. Although some traffic is inactive – *i.e.* does not entail sitting and actively working on the computer – the majority of the traffic is still generated by Web browsing and real-time communication and entertainment.

12 Grimes *et al.* (2009) find no difference in productivity between firms connected to ADSL versus firms connected to (usually faster) cable. However, the specific cable connections they looked at in their study do not allow much higher access speeds than ADSL, casting a shadow on their results.

by 30 percent according to conservative estimates, full adoption of cloud solutions by all European SMEs would lead to productivity gains of some EUR 23-32 billion per year, equivalent to 0.7-1.0 percent of value-added. Although it is unrealistic to expect full adoption of the service, this simple example provides an interesting illustration of the potential productivity gains from NGNs – that is, full adoption of a single application (cloud computing) only within SMEs would generate economic gains over the next 10 years outweighing the cost of deploying nation-wide FTTH network in the EU. Further benefits are likely to derive from large corporations as well. For instance, OECD (2009) calculates that cost savings in the range of 0.5-1.5 percent just in the four sectors electricity, education, transport and health – industries typically consisting of large corporations – would justify building a national FTTH network in the EU. However, it needs to be acknowledged that the majority of the large corporations are already connected to fibre networks, and therefore the additional productivity potential indeed lies in SMEs.

Further fibre deployment would provide substantial benefits to small and medium-sized enterprises.

Figure 13. Speed requirements of different applications



Notes: The figure illustrates the upload and download speeds required for different services (loosely based on El-Darwiche *et al.* 2009). How the services are defined has a great impact on the required speeds.

Finally, regarding "doing new things and transformations", the potential economic benefits are difficult to assess due to the obvious lack of knowledge of such applications. Nonetheless, it is argued that the ever increasing consumer demand for sufficient bandwidth to support new applications and services creates the context for change in building NGNs (*e.g.* El-Darwiche *et al.* 2009). However, certain trends can be foreseen which create different requirements for these networks. Firstly, increasing advancements in imaging technologies (*e.g.* electronic microscopes, cameras *etc.*) across industries increases the need for networks which enable the transfer of large amounts of data in a short period. Secondly, the growing popularity of remote hosting, multi-location collaboration and cloud computing applications emphasizes the importance of two-way traffic, and therefore the need of network infrastructures capable of providing sufficient upload speeds.

The environment-related economic benefits from higher access speed networks derive from the services they enable. For instance, a recent study indicates that, along with the other cost savings, SMEs can decrease IT-related carbon emissions by 80 to 90 percent by adopting cloud services (Salesforce 2011). Another recent study (Ecobilan 2008) finds that fibre-enabled reductions in travel thanks to tele-working and telemedicine only would result in emission reductions of 330 kg of CO2 equivalent per user over 15 years. Accordingly, a 1-percent increase in FTTx use in the EU would result in CO2 savings of over 100 ktons per year.

Overall, GSM Association (2009) estimates that advances in mobile broadband alone would add 0.5-1.0 percent to GDP in the in EU annually to 2015, entailing a cumulative increase by EUR 340-750 billion in the level of EU GDP from 2010 to 2015 – well above the estimated amount required for reaching the DA targets in any scenario. Fibre-based networks are likely to have a greater impact due to the higher quality of service, although lacking the value of mobility. Nevertheless, it needs to be noted that the economic benefits quoted by a number of earlier studies remain limited to current applications and solutions – and the applications are still limited due to a lack of fibre infrastructures. Value-adding services will be developed once the infrastructure is in place to enable them, not the other way around. In fact, Rosston *et al.* (2010) find that the average household is willing to pay about USD 45 per month to move from "slow" to "fast" broadband, but it is willing to pay only USD 3 per month to move from "fast" to "very fast" speeds. This suggests that consumers at least do not see the additional value of having super-fast broadband at the moment. However, the willingness to pay tends to grow as customers get used to better-quality services. Therefore, the economic benefits described are just the baseline, with likely upsides deriving from future applications and service development.

8. Public support mechanisms for NGNs

The EU has adopted guidelines on how to apply state aid rules to the public funding of broadband networks in general and NGN deployment in particular.

Policy makers in Europe have, in light of the Digital Agenda, initiated a discussion on how governments and the public sector should support the deployment of next generation networks[13] – basing the need of such networks on high economic benefits. The European Commission has adopted guidelines on the application of EC Treaty state aid rules to the public funding of broadband networks. These guidelines aim to provide a clear and predictable framework for stakeholders and will help the EU member states to accelerate and extend broadband deployment. Separate guidelines were recently developed with respect to state aid rules regarding NGN deployments (European Commission 2010b). Furthermore, it is stated in the Europe 2020 Strategy that the Commission is committed to providing a legal framework that stimulates investment in an open and competitive high-speed Internet infrastructure, and overall, to promote Internet access and take-up by all European citizens. Member states are expected to further polish their legal frameworks for coordinating public works to reduce the cost of network roll-out, and to draw up operational strategies including the provision of basic broadband and NGNs (including targets for public funding in areas not fully served by private investment) to reach the targets set in the DA.

There is a large literature on the role of the public sector in supporting broadband deployments (Table 2), see *e.g.* Friedrich *et al.* 2009; Nucciarelli *et al.* 2010. According to Friedrich *et al.* (2009), the level of government involvement can vary from being an observer (*e.g.* US and Germany), to being a facilitator (Sweden and Norway) or even a driver (Japan and South Korea). In addition to setting regulatory parameters for NGN deployment, government intervention can further take place through direct subsidization or co-development initiatives (also referred to as public-private partnerships or PPPs).

One of the key regulatory concerns relate to principles of access – not only to cables but also to the ducts and buildings. Gryseels and Begonha (2010), for instance, estimate that 40 to 50 percent of the fibre deployment business case can depend on the appropriate regulatory regime. However, the

13 Within the European Commission, the discussion on financing broadband and NGNs followed directly after the introduction of the Digital Agenda (European Commission 2010a).

regulatory setting is multifaceted due to various technological and commercial aspects. Although right regulatory measures could prevent parallel and redundant network deployments by supporting network sharing, wrongly set tariff and/or access principles might limit competition. Still, by setting appropriate regulatory parameters, countries could ensure maximum coverage for any given level of market-driven investment while ensuring a competitive market environment.

Nevertheless, while appropriate and effective regulation is the key foundation enabling investment into NGNs, it does not directly attract investment. Regulation can lower the risk of deployment for the private sector while ensuring sufficient competition. Measures to oblige operators to roll out NGNs, similar to basic broadband through universal service obligations (USO) in some countries, are unlikely due to the large financing need and are in fact only efficient to reach the "last corners".

The simplest model of government intervention is direct subsidization – *i.e.* state aid. This model involves a private sector operator receiving some level of public funding (often a grant) to assist in its deployment of a new network offering open wholesale access. The operator retains full ownership of the network (a valuable long-term asset for the operator) and the public sector is not involved in running the network.

As a variant to direct subsidization, government may subsidize by bringing down the cost of finance and by providing access to long-term finance. For instance, if in the financing-gap assessment discussed in Section 6, a WACC of 5 percent was used instead of 10 percent, the capex thresholds for market-driven investments would increase by 20 percent. Similarly, it may be difficult for market operators to find long-term credit exceeding 10 years. Therefore, enabling such finance would bring down the cost and risk of deployment.

As a variant to direct subsidization, the government may bring down the cost of finance and provide access to long-term finance.

Other methods of direct subsidization relate to direct deployment grants, brining down the capex itself and therefore significantly improving the business case for private operators. However, since the economic benefits of NGNs derive from the uptake and use of services and not from coverage, the question arises whether to subsidize the uptake rather than the deployment *per se*. This can be done either by subsidizing (securing) a certain level of uptake to make the business case viable, or by directly stimulating demand for the network, be it by direct use in the public sector or by subsidizing consumer uptake of NGNs (see *e.g.* Friedrich *et al.* 2009 for illustrative examples). However, the key problem with direct subsidization is the availability of public funds and the fact that the private sector still needs to initiate, design and sometimes even implement these deployment projects even before any agreement on possible subsidies. Governments can also apply tax instruments (*e.g.* exemptions) that can be applied to support NGN deployments, which may significantly improve the financial viability of the deployment.

In respect of co-development (PPPs), different models vary from public outsourcing to joint ventures and fully public DBO (design, build, operate). In public outsourcing, a public-sector body outsources network build and operation to the private sector organisation under a long-term agreement, while retaining the ownership of the network. A joint venture is any agreement whereby ownership of the network is split between the public and private sector. Construction and operational functions are likely to be undertaken by a private sector organisation. In public DBO, all aspects of network deployment and operation are managed by the public sector. Although these three models are persistent, the level of public sector risk and involvement may significantly differ even within the different types of co-development projects. Although in all co-development models, the public sector can add financial stability and risk sharing ability to projects, public-sector involvement also adds a layer of bureaucracy to the deployment and bears the potential for conflicts of interest.

Table 2. Advantages and disadvantages of different modes of public intervention

	Regulatory setting	Financial support	Co-development
Advantages	Does not impose any financial burden on the public sector Can lower the risk of deployment for the private sector while ensuring sufficient competition	Can lead to faster deployments More suitable for funding widespread deployments as the public funding can be given to an established commercial operator to deploy and operate the network	Combines public-sector financial stability with private expertise Allows different business models Public sector retains a certain level of control and can ensure that socio-economic objectives are met
Disadvantages	A tool to remove barriers to investment, yet alone not sufficient to attract private investment to NGN	Private sector still needs to initiate projects Limited ability to ensure that socio-economic objectives are met	Added bureaucracy to deployment and potential conflicts of interest

Public funding to the industry appears to work for large-scale roll-outs, but setting the appropriate subsidy level is a challenge.

Overall, the historical evidence from Japan and Korea, for instance, shows that a solution delivering funding to the industry appears to work for large-scale roll-outs (see *e.g.* Gryseels and Begonha 2010). The most problematic issue to assess is the level of public sector involvement, which is closely related to the commercial viability of the roll-out. While the problem of direct deployment grants lies in assessing their appropriate levels, also to avoid subsidization of competitive areas, the difficulty of PPP models seems to lie in the added layer of bureaucracy affecting the speed of deployment. One thing is sure, however: there is no one model that fits all. Rather, the appropriate policy mix depends on a number of factors including the characteristics of the area, the available technologies, and demand factors.

9. Summary and discussion

The aim of this paper has been to investigate the cost, financing gap, added economic value, and finance mechanisms of the potential deployment of NGNs in Europe. The paper builds on the specific broadband targets set forward in the Digital Agenda for Europe initiative by the European Commission which, although being fairly open to different interpretations, provides a sufficient understanding of the broadband development objectives in Europe for the coming years. The paper has taken a specific look at the Commission's targets to deploy super-fast broadband infrastructures in Europe, namely fibre-based next generation networks.

In Europe the use and availability of broadband technologies allowing super-fast broadband access is still lagging behind other digitally developed nations. FTTH coverage for instance is less than 10 percent of the European households. The average download speed of a broadband connection in Europe is 5 Mbps, and only 30 percent of the total broadband subscriptions are over 5 Mbps. This imposes significant need for development of broadband infrastructures, if the targets of 30 Mbps and 100 Mbps connectivity set in the Digital Agenda are to be met. The cost assessment provided in the article shows that overall an investment of between EUR 73 and EUR 221 billion would be required over the next 10 years in order to fulfil all the DA broadband targets, over 75 percent of which would be required for reaching Targets 2 and 3, *i.e.* those specifically referring to high access speeds. The wide range in the cost estimate is due to a vague description of the targets, leading to several possible interpretations, with each of them leading to a different set of technological options. In further analysis, this paper has interpreted the targets as meaning actual (as opposed to theoretical or advertised) speeds as this is what matters in assessing the real economic impact.

Overall, it has been estimated that to deploy a full EU-wide FTTH network, an investment of EUR 209 billion would be required. 50 percent of this cost would be required to cover 80 percent of the households located in urban and suburban areas in Europe, while the other 50 percent of the cost would be required to cover the remaining 20 percent of households located in rural areas. This raises two policy issues. For one thing, market-driven deployment alone is likely to be geographically unbalanced, favouring urban areas. What is more, total available private finance will not suffice to meet the targets of the Digital Agenda – a financing gap remains. It was estimated that market driven investments could cover up to 70 percent of the European population with FTTH networks, corresponding to 35 percent of the total investment requirement, through deployment of proprietary networks or with private-sector, collaborative deployment schemes. This coverage is, however, limited due to market imperfections. A sanity check of this bottom-up approach was done by examining the market's affordability to invest, which showed that the market cap for investments into FTTH infrastructures in fact lies at a level of EUR 10 billion per year, which over a 10-year horizon would correspond to less than 50 percent of the total investment requirement. Accordingly, public intervention would be called for to reach the DA targets.

Deploying a full EU-wide FTTH network would require investing EUR 209bn – half of it to reach the 20 percent of households living in rural areas.

However, there need to be economic benefits to society from these super-fast broadband networks to justify government intervention. There exists a wide literature on the socio-economic benefits of telecommunications, Internet and further broadband, emphasizing the positive impacts on GDP growth and productivity, education and healthcare, energy, social inclusion and so on. However, there have been only few attempts to assess the return on bandwidth, that is, what are the additional benefits of upgrading from basic broadband to super-fast broadband. The economic argument of NGNs lies in the fact that it enables (i) doing what people do now more productively (the value of time savings); (ii) doing more utilizing existing applications; and (iii) doing new things and transformations. Regarding point one, it has been calculated as an example that an average time saving of only 1 minute per working age inhabitant every day would lead to economic benefits from time savings equal to the cost of full fibre deployment. On point two, it has been calculated that full adoption of cloud services enabled by NGNs only within the SME sector would lead to productivity gains beyond the cost of deployment. The economic benefits of point three cannot be assessed due to the fact that these services are still non-existent.

Therefore, it seems there is high potential for economic benefits, which would in principle justify public sector intervention. In addition to setting regulatory parameters in such a way as to support market-driven investment, public intervention could be done through direct subsidization of capex of service uptake, or through various collaborative development schemes whereby the public sector would be involved, most often together with private parties, in designing, building and/or operating the network. There is no one model that fits all, and public intervention requires careful assessment of the environment. However, one needs to keep in mind when designing models for public intervention that there is a general misinterpretation when it is claimed that network deployments will lead to economic benefits, where in fact it is the uptake and use of the service. This is particularly true in the context of the planned NGN deployments where consumers still fail to see the additional value of super-fast broadband compared to fast broadband.

Finally, the following outcomes from the analysis in this paper are of interest for policy makers. First, while most people refer to broadband speeds as download speeds, upload speeds are in fact becoming increasingly important as the key services providing economic value-added enabled by NGNs require two-way symmetric access (*e.g.* cloud computing, multi-location collaboration *etc.*). In fact, upstream traffic already accounts for over 20 percent of the total traffic of an average fixed broadband user (Sandvine 2011), and this share is constantly increasing.

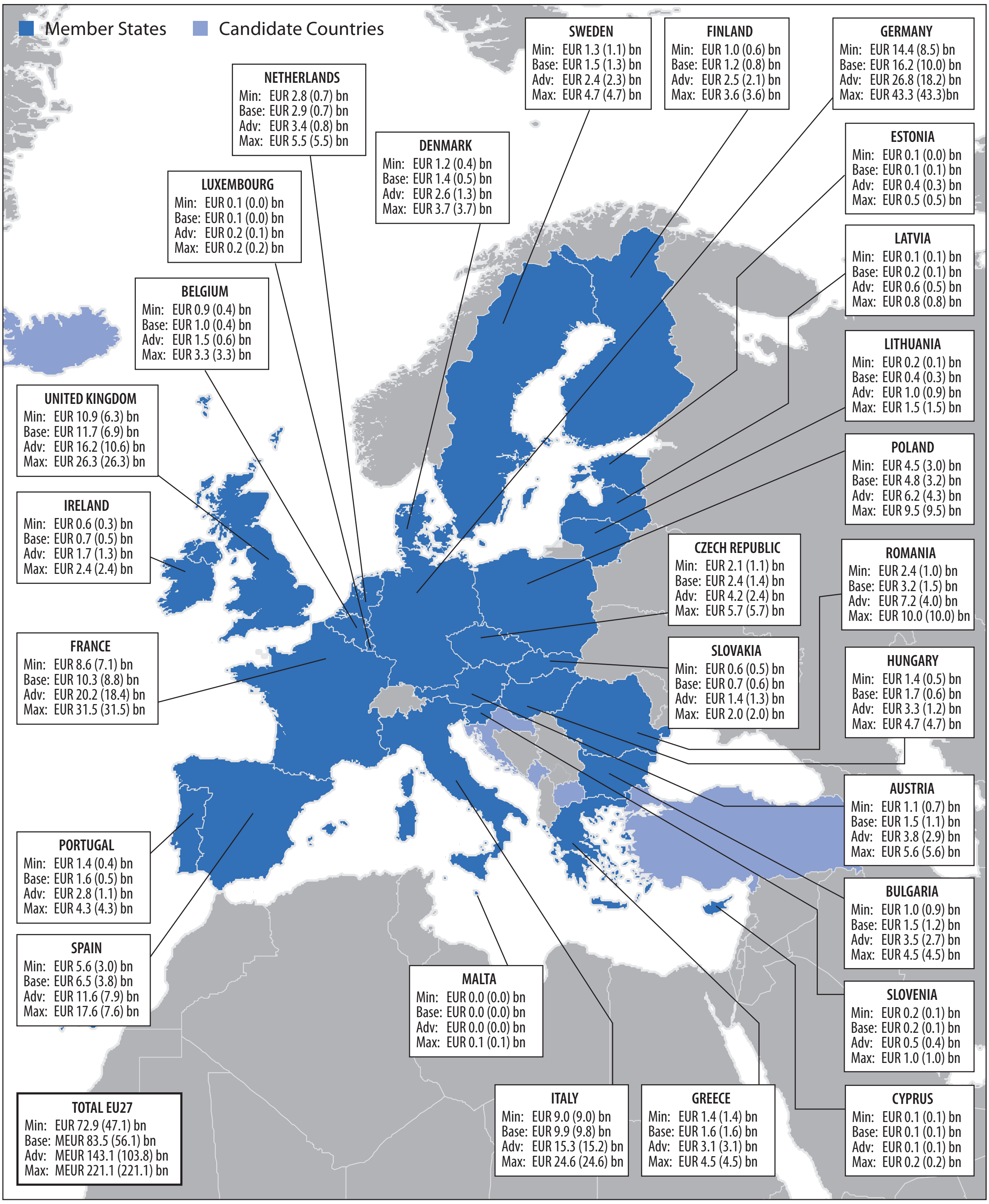
Second, while the uptake of NGNs unlocks certain economic benefits, it is the services they enable that provide the additional benefits. Therefore, new applications and service development should not be overlooked. It is reasonable to argue that there are increasing economic returns to bandwidth, yet decreasing returns to scale. This means that, although a 100 Mbps connection provides added economic value over a 2 Mbps connection, the 2 Mbps connection carries a significantly higher economic return per bit than a 100 Mbps connection. However, this nonlinearity is likely to be slightly corrected as new bandwidth-hungry applications are introduced requiring super-fast connection.

Concentrating government support on rural areas would also help to meet digital-inclusion and regional-convergence targets.

Third, from the perspective of digital inclusion and regional development it is imperative that the public sector support fibre deployment in rural areas, although the DA implicitly limits its 100 Mbps targets to urban areas. Therefore, fibre deployments focusing only on urban and suburban areas would lead to greater imbalance in digital inclusion, have a negative effect on regional development, and lead to negative congestion externalities by fostering agglomeration of economic activity in the better-connected urban and suburban areas.

Finally, in fibre deployment, increasing cross-industrial cooperation is called for. Recent studies (*e.g.* Kenny and Kenny 2011) suggest that installing fibre during road construction adds only about one percent to total construction cost. Given that an estimated 70 to 80 percent of the cost of fibre deployments relate to civil works, *i.e.* digging the ducts where fibre is laid, there are a lot of synergies to be attained from cooperation with industries in charge of roads, electricity, and water and sanitation.

Annex 1. Total costs by country in all scenarios



Notes: Cost figures presented without brackets describe the total cost excluding cable in the calculation while figures in brackets represent total cost if the existing cable infrastructure is fully considered.
The four scenarios (Minimum, Base, Advanced, Maximum) refer to different levels of quality in fulfilling the Digital Agenda targets (see Section 5.1).

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ABSTRACT

The revival in US productivity growth since the mid-1990s is linked to a surge in investment in information and communication technologies (ICT). *Against the backdrop of a weakening link between productivity and traditional innovation inputs (e.g. R&D expenditure), digitization has spurred productivity through innovations in management techniques, business models, work processes and human resource practices. More fundamentally, digitization is changing the way innovation itself is done, opening the prospect of a long-term increase in the overall rate of innovation. Over time, this will dwarf the benefits from any particular innovation. Digitization is transforming innovation in four ways: 1) improved real-time measurement of business activities; 2) faster and cheaper business experimentation; 3) more widespread and easier sharing of ideas; and 4) the ability to replicate innovations more quickly and more accurately. This mutually reinforcing sequence amounts to a new kind of R&D, with far-reaching implications for public policy.*

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ICT, innovation and the e-economy

Erik Brynjolfsson

1. Introduction

In the long run, our living standards depend on productivity growth. In turn, productivity growth depends on innovation. This makes innovation a critical concern for policymakers, managers and economists. Unfortunately, the effectiveness of traditional innovative inputs appears to have grown weaker over time. While investments in R&D, the number of scientists, and scientific publications have all grown for over a century, productivity growth has not increased commensurately.

More recently, there has been a resurgence in productivity growth and this offers hope for the future of innovation. In particular, innovation in digital technologies has increased, creating a vibrant "e-economy". This has affected both productivity and innovation in the rest of the economy as well.

Digital innovations drive productivity in three ways. First, they directly increase productivity through the simple mechanics of growth accounting. The quality-adjusted price of information and communication technologies (ICT) has dropped precipitously. Because the real quantity of computer power has grown even more rapidly, this price decline, when multiplied by the stable or growing expenditure share of ICT in GDP automatically generates a contribution to national productivity growth. For instance, in recent years, high tech has accounted for over one third of the rise in productivity in the US despite directly accounting for only about 5 percent of the inputs.

Second, digitization has spurred other innovations. In particular, firms have invested heavily in innovative management techniques, business models, work processes, and human resource practices which complement and amplify their ICT investments. These complementary organizational investments are typically several times larger than the direct investment in ICT and account for well over a trillion of dollars of intangible capital in American firms (Brynjolfsson *et al.* 2002).[1]

Third, and perhaps most importantly, digitization is changing the way innovation itself is done. This is especially evident in information industries, but it is increasingly important in other areas of the economy as well. Over time, the benefits from increasing the rate of innovation will dwarf the benefits from any single innovation. However, the ways that ICT is transforming innovation are not yet well understood. Accordingly, I will devote more of my discussion to this aspect of digitization.

In this paper, I will first briefly highlight three important insights from research on innovation. I will then describe some evidence on how both the mean and dispersion of productivity growth has increased. Turning specifically to digitization, I will explain four ways that digitization is accelerating innovation: via measurement, experimentation, sharing and replication. These changes are especially evident in the Internet-based firms at the core of the e-economy, but are increasingly diffusing to firms in all sectors. In fact, they portend a long-term increase in the overall rate of innovation. Finally, I will provide some policy implications and conclude with some thoughts about future productivity growth.

1 See also Brynjolfsson and Hitt (2000), Bresnahan *et al.* (2002), Bartel *et al.* (2007) and Bloom *et al.* (2007).

2. Three stylized facts about innovation

While the economic literature on innovation is vast – certainly too voluminous to summarize in this brief paper – three facts are important to keep in mind:

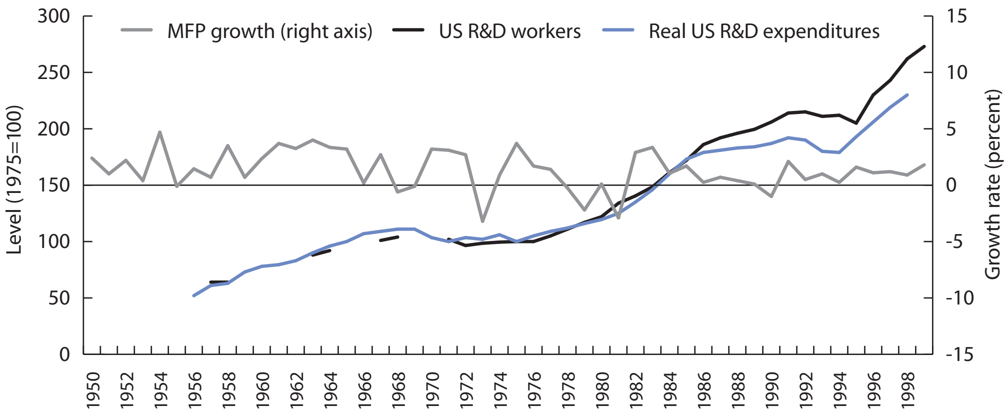
1. Although *inputs* to innovation, by almost every measure, have been rising significantly over the past century, *output*, as measured by the trend growth rate of multifactor productivity (MFP), has been flat.
2. There are dramatic differences among regions, industries and firms in their effectiveness at generating innovations.
3. The effect of an innovation on living standards depends on how much of the economy it affects.

2.1 Growing innovation inputs without growing productivity

An R&D worker was associated with seven times as much MFP growth in 1950 as in 2000.

Of these points, the first one is the cause for greatest concern. As shown in Figure 1, each R&D worker was associated with about seven times as much MFP growth in 1950 as in 2000. Other metrics show similar patterns (Jones, forthcoming; Azoulay and Jones 2006).

Figure 1. Higher R&D spending has not translated into higher productivity growth



Source: Azoulay and Jones (2006)

Perhaps this discrepancy is merely an artefact of mismeasurement. After all, many of the sources of value in the modern economy are not reflected in the productivity statistics. Alternatively, it may be a real phenomenon. If we have "fished out" all the easy innovations, it requires more and more effort to get each incremental improvement in MFP. Let's look at each of these possibilities in turn.

2.1.1 Mismeasurement

The growth rate in MFP is derived from the national accounts. In turn, converting nominal GDP to real values depends on the price deflators. However, in an increasingly digital world, more and more goods are being delivered for free, earning them a weight of zero in the GDP statistics. A typical American teenager might spend the majority of his leisure time consuming services from Facebook, YouTube, and Twitter. Not only did none of these services exist a generation ago, but all of them are free. While improvements in the price and quality of broadband Internet service – delivering the bits – are reflected in the productivity statistics, the explosion in value of the content, including virtually all the millions of new sites on the World Wide Web, is not. In fact, industries like news and music appear to be shrinking, at least when measured by revenues, as they become more digital.[2]

2 Between 2004 and 2008, the music industry's revenues from physical shipments and digital downloads shrank from USD 12.34 billion to USD 7.39 billion.

Increased product variety is another change in the economy that is not fully reflected in the productivity statistics. While the typical physical bookstore has about 40,000 book titles, Amazon carries over three million, generating over a billion dollars of consumer surplus just from the increased choice (Brynjolfsson *et al.* 2003). In the broader economy, the number of trademarks and stock-keeping units has grown dramatically, and the welfare benefits of this variety are not fully reflected in the productivity numbers (Brynjolfsson 1996). Mismeasurement may explain part of the productivity shortfall, but it is important to bear in mind that some output went unmeasured in earlier eras as well. For measurement to be the main explanation, it must be getting worse over time.

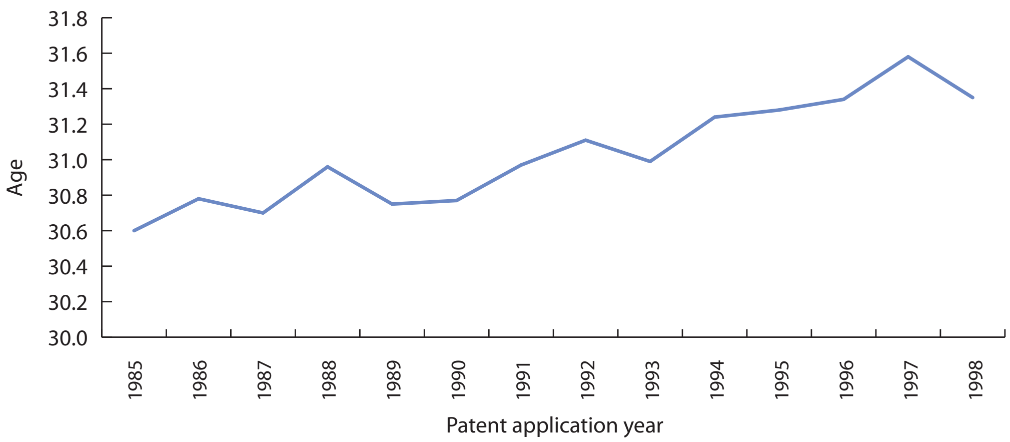
2.1.2 Fishing out

The more troubling explanation for the declining ratio of MFP growth to R&D investment is that we have begun fishing out the easy innovations. Ben Jones makes a compelling case that the "burden of knowledge" has grown. Over time, there is more and more existing knowledge that must be learned before reaching the frontier, retarding the efficiency of innovators and forcing them to specialize more narrowly. This hypothesis has three testable implications. Over time, inventors are older at the time of their first innovation, they are less likely to switch fields, and, having specialized, they are more likely to work with collaborators, who may have complementary knowledge. Each of these implications appears to be true (Figure 2).

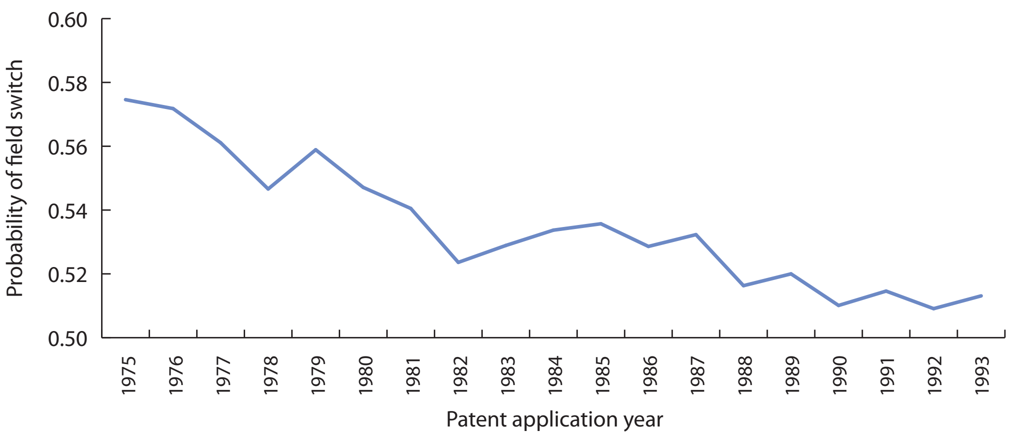
Apart from mismeasurement, the declining ratio of MFP growth to R&D investment might reflect a growing burden of knowledge.

Figure 2. Evidence of a growing burden of knowledge

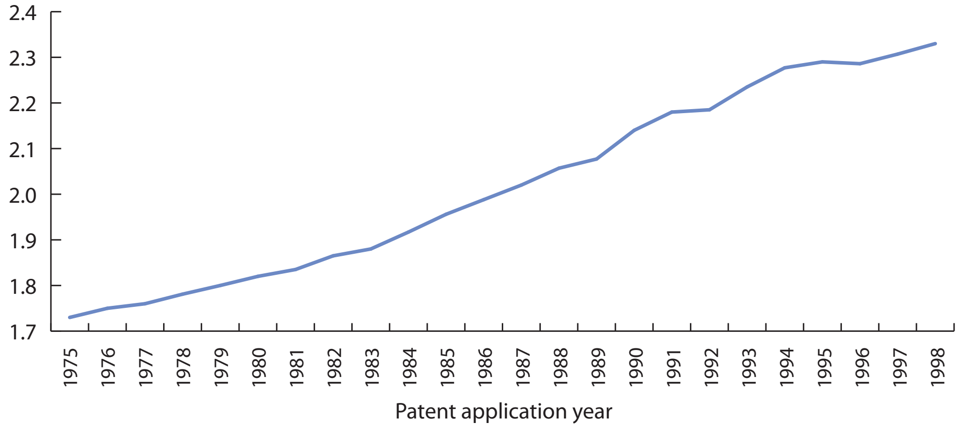
2a. Trend age at "first innovation"



2b. Trend in field switch for fast innovators



2c. Trend in average inventors per patent



Source: Jones (forthcoming)

2.2 Unevenness in innovative activity

There is enormous variability across regions, industries, firms and time in the innovation output per dollar of R&D.

While the innovation output per dollar of R&D may be declining overall, there is enormous variability across regions, industries, firms and time periods. A small number of regions such as Silicon Valley produce a vastly disproportionate number of innovations. Some individual laboratories, like the one run by Eric Lander in Cambridge, Massachusetts, produce more patents each year than some entire nations, such as Sri Lanka. The pharmaceuticals, information technology, telecommunications and medical devices industries produce disruptive waves of innovation each decade, while other industries, like automobiles, produce a product that has not fundamentally changed in over half a century. This does not simply reflect differences in investment: in 2007, GM's R&D budget was the largest of any company in America and automobile companies accounted for three of the top four R&D spenders in the world (Hira and Ross 2008).

This unevenness suggests that we may be able to draw lessons from the more innovative sectors of the economy. For instance, the Internet sector has experienced a wave of innovation, with companies like Google creating billions of dollars of shareholder value, and billions more in consumer surplus, with entirely new products and services in a relatively short period of time. While these companies often do have formal R&D budgets, employ scientists of various types, and may patent some of their inventions, many of their innovations do not follow this conventional path. They may innovate in business models, business processes, delivery methods and product features and these innovations may be developed by managers, engineers, or even customers, outside of any formal R&D budget and without any formal intellectual property (IP) protection.[3] More broadly, ICT has set in motion a collection of business innovations that are profoundly affecting industries from retailing, media and manufacturing to finance, transportation and consulting.

2.3 The effect of innovations on living standards depend on expenditure shares

No matter how dramatically an innovation changes a good or service, its impact on GDP will be limited if that good or service is a small share of the economy. Furthermore, when an innovation leads to lower

3 As a result, these types of innovation may not be well captured by traditional metrics of innovation such as patents and other forms of intellectual property, R&D spending, and counts of scientists or their publications, exacerbating the mismeasurement problem discussed above. For instance, most organizational and process innovations are not developed by scientists via the traditional R&D process and are never patented. Similarly, there have been a plethora of important human resource innovations that measurably affect productivity (Gant *et al.* 2002).

prices, then the share of the GDP devoted to that good or service will decline if the good is price inelastic. In turn, this will reduce the productivity benefits to the overall economy from further technological improvements for that good or service.

This fact is the source of "Baumol's disease" – sectors with high productivity growth often tend to shrink as a share of the economy (Baumol 1967). However, there is no economic law that requires expenditure shares to always shrink as prices decline. When goods have price elasticity of demand greater than one, then price declines lead to a *growing* share of expenditure. This has historically been the case for ICT (Brynjolfsson 1996) at least until recently. Thus, the relatively steady, exponential improvements of Moore's Law[4] have resulted in ever greater contributions to national productivity over time.

However, as long as an innovation only affects any one sector of the economy, it will have relatively limited effects on productivity. The greatest effects occur when the innovation can affect multiple sectors. This is why general-purpose technologies like the steam engine, electricity and today, ICT, can have a more revolutionary impact on living standards. In particular, when ICT is a catalyst for complementary co-inventions, its effects can be multiplied.

ICT can affect multiple sectors and is a catalyst for complementary co-inventions.

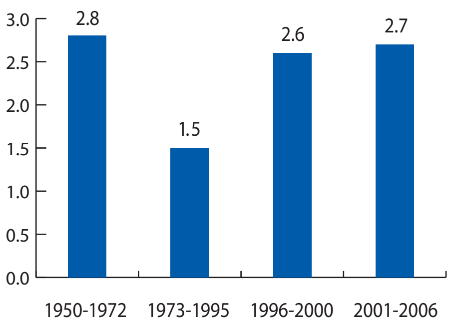
3. Productivity growth and dispersion

3.1 Productivity growth

There is evidence that ICT-enabled innovations have collectively begun to increase the productivity growth rate in recent years. In the United States, productivity growth slowed down in the early 1970s and remained relatively low through the mid-1990s. It then experienced a resurgence, continuing through the past decade (Figure 3a). Interestingly, other industrialized nations have not experienced this productivity surge (Figure 3b).

Figure 3a. Labour productivity growth has increased in the US

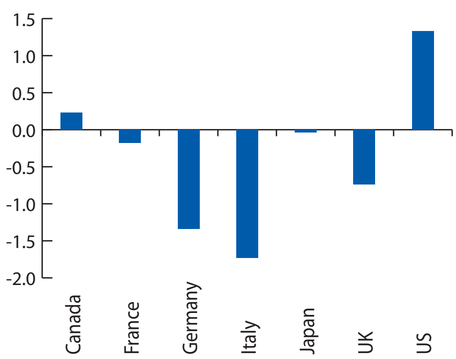
Average annual change in US labour productivity, 1952-2006 (percent)



Source: Bureau of Labor Statistics

Figure 3b. Labour productivity growth has fallen in most G7 nations since the 1990s

Difference in average annual labour productivity growth between 1995-2005 and 1990-1995 (percentage points)



Source: Organization for Economic Co-operation and Development

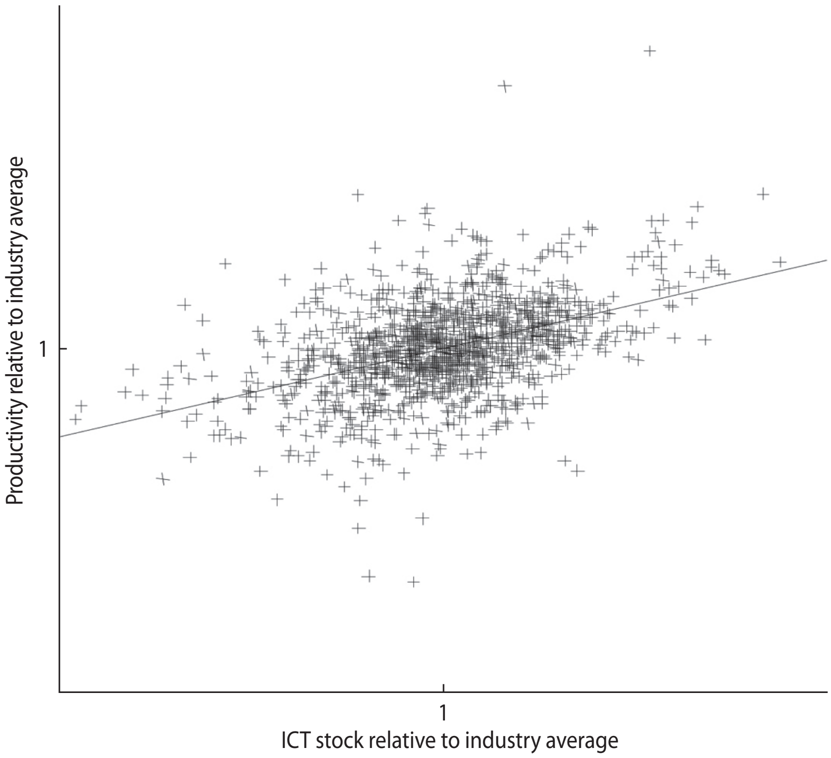
4 The doubling of transistors per chip approximately every18 months is known as Moore's Law, although the term is also applied to similar improvements in other dimensions of ICT such as storage and communications.

The surge in US productivity is correlated with increased investment in ICT. A careful growth accounting by Oliner *et al.* (2007) finds that ICT was a key factor in this resurgence. This is consistent with a similar analysis by Jorgenson *et al.* (2004) who conclude that "A consensus has emerged that a large portion of the acceleration through 2000 can be traced to the sectors of the economy that produce information technology or use IT equipment and software most intensively."

American firms are adept at implementing the management practices that maximize the value of ICT.

Furthermore, Stiroh (2002) finds that industries that are heavier users of ICT tend to be more productive. The correlation is also present at the level of individual firms. Companies that use more ICT tend to have higher levels of productivity and faster productivity growth than their industry competitors (Brynjolfsson and Hitt 2000). Bloom *et al.* (2007) find that American firms are particularly adept at implementing the management practices that maximize the value of ICT.

Figure 4. Productivity and ICT in large US firms



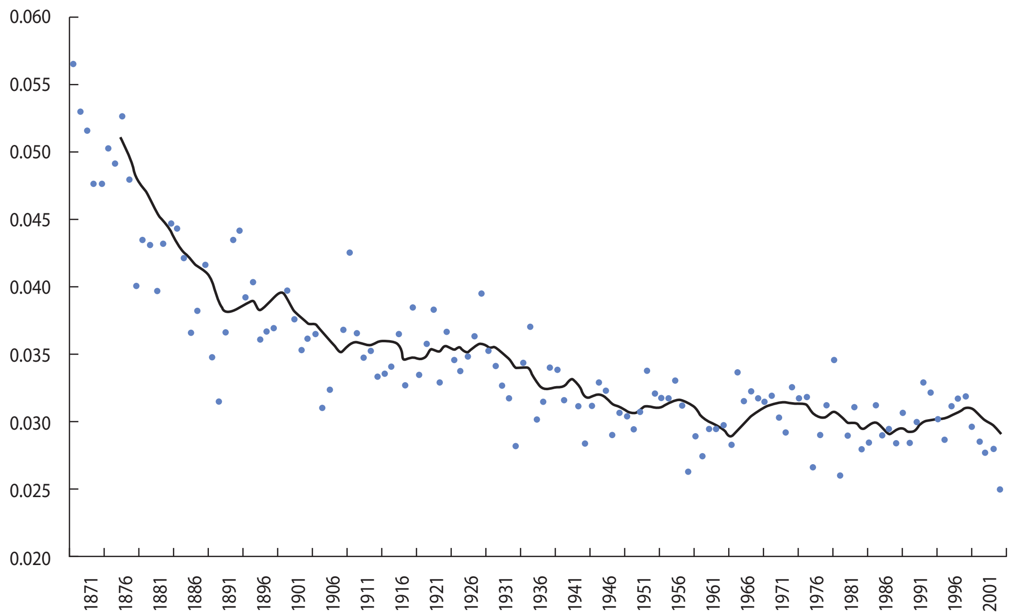
Source: Brynjolfsson and Hitt (2000)

3.2 Productivity dispersion

While productivity growth is strong evidence of innovation, Figure 4 also reveals a striking amount of variation in productivity across firms in the US economy. This variation also says a lot about the diffusion of innovation across firms. As Gould (1996) notes, "Complex systems improve when the best performers play by the same rules over extended periods of time. As systems improve, they equilibrate and variation decreases." For instance, the rules and technology of baseball have remained largely unchanged for over a century. Figure 5 shows how the variation in baseball batting averages has declined during that period. This reflects the asymptotic limits of human performance and the elimination of ineffective techniques and training methods as better ones were adopted.

Figure 5. Decreasing dispersion in baseball batting averages since the 1870s

Standard deviation by year, all major league players



If there were no innovation in the technology and rules that govern production, distribution, and other aspects of business, one might also expect that variation in performance would decrease asymptotically over time, as existing innovations diffused and firms far from the frontier exited. Conversely, periods of faster innovation are likely to be reflected in increased dispersion in performance.

So what do the data show?

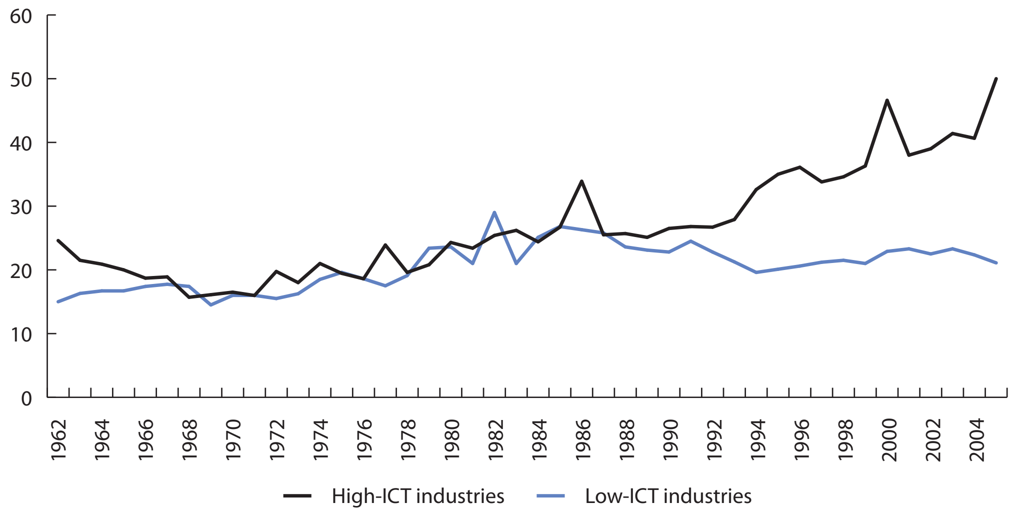
Since the mid-1990s, the gap between leaders and laggards has grown overall in the US economy. For instance, the interquartile range or IQR (the difference between the firm at the 75th percentile and the firm at the 25th percentile) in gross profit margin held steady at about 20 percentage points throughout the 1960s, 1970s and 1980s, but in the mid-1990s it started to increase substantially and by 2006 it was nearly 35 percentage points (Brynjofsson *et al.* 2009). This increase in performance spread coincides with the surge in the overall productivity growth rate of the US economy starting in 1995, and has continued through boom and recession. These results are consistent with the idea that there was a broad-based innovation or cluster of innovations, a "rules change", in the mid-1990s. This gave some firms a competitive advantage over others and increased the overall rate of technological progress.

Periods of faster innovation like the one since the mid-1990s are characterized by increased dispersion in performance.

The increase in performance spread has not occurred equally in all industries. Those with relatively higher levels of R&D spending tend to have slightly greater dispersion in these metrics. This is consistent with the idea that innovation increases performance heterogeneity. However, since the mid-1990s, ICT intensity has been a much stronger correlate of performance spread. The IQR for gross profit margin roughly doubled in the 31 industries with the highest ICT intensity while it was largely unchanged in the 31 industries where ICT intensity was below the median (Figure 6). Other performance metrics show a similar pattern, including EBIDTA margin, Return on Assets, Return on Equity, Tobin's Q, and the ratio of market value to revenue.

Figure 6. Increasing dispersion in business performance in ICT-using industries

Inter-quartile range in gross profit margin, 1962-2005



Source: Brynjolfsson *et al.* (2009)

Thus, whatever the underlying drivers are behind the increase in both productivity growth and the dispersion of performance, they appear to be strongly correlated with the use of ICT.

4. How digitization is transforming innovation

While the exponential improvements in the power of digital technologies have been remarkably consistent for over 40 years, the absolute magnitudes of the increases are, of course, much larger in recent years. For instance, the number of bits stored digitally has doubled roughly every 18 months. Thus, the number of digital bits newly stored in the past 1.5 years is as great as the digital storage from all previous years combined. Meanwhile, networking and software have become much more pervasive. The widespread use of the Internet by consumers and businesses since the mid-1990 is a particularly visible example, but the adoption of enterprise information technology by most major corporations is probably even more important for productivity and business innovation.

There is a long tradition in economics of modelling both markets and organizations as information processors (*e.g.* Hayek 1945; Sah and Stiglitz 1986). As a result, it would be surprising if the large drop in the cost of digital information processing did not have significant effects on business models and business process innovation, and indeed, on the organization of innovative activities themselves.

Digitization has enabled four important trends relevant for innovation.

The increasing digitization of economic activities has made possible four important trends, each of which has significant implications for innovation:

- Improved real-time, fine-grained measurement of business activities;
- Faster and cheaper business experimentation;
- More widespread and easier sharing of observations and ideas; and
- The ability to replicate process and product innovations with greater speed and fidelity.

While these are certainly not the only ways that digitization is affecting innovation, they are each important in a significant and growing number of firms. In the next four sub-sections, I will briefly describe each of these trends, and then discuss how they complement each other to accelerate innovation.

4.1 Measure: Digitization makes it possible to measure activities in real time and with great precision

Historically, revolutions in measurement have engendered revolutions in innovation. For instance, when Anton van Leeuwenhoek developed an improved microscope and documented the existence of tiny "animalcules" in water droplets and human blood, it provided the foundation for the germ theory of disease and eventually a host of medicines and treatments.

Historically, revolutions in measurement have engendered revolutions in innovation.

Today, businesses have begun gathering extremely detailed data on their activities and customer relationships. This is particularly evident in the e-economy, where click-stream data give precisely targeted and real-time insights into consumer behaviour. Anyone with access to a web browser can get summaries of billions of keyword searches, and this information is highly predictive of present and future economic activity, such as housing purchases and prices (Wu and Brynjolfsson 2009). Mobile phones, automobiles, factory automation systems and other devices are routinely instrumented to generate streams of data on their activities, making possible an emerging field of "reality mining" to analyze this information (Pentland 2008). Manufacturers and retailers use RFID tags to deliver terabits of data on inventories and supplier interactions and then feed this information into analytical models to optimize and reinvent their business processes.

Much of this information is generated as a costless by-product of computerization, and sits unused, at least initially. A few years after installing a large enterprise resource planning (ERP) system, it is common for companies to purchase a "business intelligence" module to try to make use of the flood of data that they now have on their operations. The aim is to identify patterns in the data and to generate and test hypotheses about potential business innovations. This is creating a shift from intuitive management to more numbers-driven decision-making. As a Microsoft researcher memorably put it, objective, fine-grained data are replacing HiPPOs (Highest-Paid Person's Opinions) as the basis for decision-making at more and more companies (Kohavi *et al.* 2007). For instance, Enologix has used this approach to help Gallo vineyards accurately predict the wine ratings that Robert Parker would give to various new wines, UPS has mined data on truck delivery times to develop a new routing method and Match.com has even developed new algorithms for matching men and women for dates (Davenport 2007). For each innovation, analysts drawing on detailed measurement have supplanted human experts who used more tacit knowledge and intuition.

4.2 Experiment: Digitization makes it possible to run business experiments much more cheaply and frequently

Examining data that have been generated as a by-product of regular operations and interactions can yield insights that drive innovation. However, it typically takes controlled experiments to determine causality. Historically, experimentation has been difficult for businesses to do outside of the laboratory because of cost, speed and convenience. While scientific thinking has been dominated by the experimental approach for nearly 400 years, an era of exceptional scientific progress, it is only relatively recently that experiments have begun to become more widespread as a tool for business innovation.

The change has been most sweeping in "born-digital" companies like Amazon and Google. A central part of Amazon's research strategy is a program of "A-B" experiments where it develops two versions of its website and offers them to matched samples of customers. Using this method, Amazon might test a new recommendation engine for books, a new service feature, a different check-out process, or

Rather than agonize for months over a choice, Internet firms ask customers and get the answer in real time.

simply a different layout or design. Because of the large number of customer interactions it processes, Amazon sometimes gets sufficient data within just a few hours to detect a statistically significant difference between the two hypothesized solutions.[5] This ability to rapidly test ideas fundamentally changes the company's mindset and approach to innovation. Rather than agonize for months over a choice, or model hypothetical scenarios, the company simply asks the customers and gets an answer in real time. Ideas that might have taken months or even years to develop and assess can now be quickly and cheaply prototyped and tested, vastly increasing the clock-speed of the innovation process.

The scale of business experimentation at some firms is prodigious. According to Hal Varian, Google runs on the order of 200-300 experiments per day, as they test new products and services, new algorithms and alternative designs. An iterative review process aggregates findings and frequently leads to further rounds of more targeted experimentation.

At the same time, Google's competitors, partners, customers and third-party consultants are doing their own experiments, creating a complex, interacting ecosystem that demands continuous innovation. While Google currently dominates the market for web search, it is unlikely that it would have any market share at all if it still relied on the original, unmodified PageRank algorithm that Larry Page and Sergey Brin developed in 1998 (Brin and Page 1998).

Greg Linden, who led one set of experiments at Amazon, describes the emerging experimentation philosophy succinctly:

> "To find high impact experiments, you need to try a lot of things. Genius is born from a thousand failures. In each failed test, you learn something that helps you find something that will work. Constant, continuous, ubiquitous experimentation is the most important thing." (Brynjolfsson and Schrage 2009)

These words echo the approach of innovators since Thomas Edison, but ICT has made it possible to apply it to a much broader class of business challenges and significantly compress the "hypothesis-to-experiment" cycle time.

While web-based companies have been particularly aggressive in using business experiments to drive innovation, digital platforms have brought this approach to other industries. For instance, Harrah's transformed itself from a second-tier casino company to the industry leader in large part because of the culture of experimentation that CEO Gary Loveman introduced. When Loveman, an economics PhD from MIT and former Harvard Business School professor, arrived at Harrah's, he found that it was already gathering a great deal of data about its customer interactions via its existing information systems and programs such as its Total Rewards loyalty card. However, it was not using these data systematically to develop improved processes, products and services. When Loveman became the CEO of Harrah's, he developed strategies to continually test new promotions, price points, services, workflow, employee incentive plans and casino layouts using controlled experiments.

Widespread business experimentation has required a fundamental change in the corporate culture. As Loveman puts it "There are two things that will get you fired from Harrah's: stealing from the company, or running an experiment without a properly designed control group" (Brynjolfsson and Schrage 2009). Meanwhile, many of Loveman's competitors have been slower to make this transition, allowing Harrah's to gain market share. Loveman does not believe that the gaming industry is uniquely

5 Jeff Wilke, Head of North American Retail, Amazon.com, personal communication.

suited to this approach – it can and has occurred in many other industries. For instance, leading firms in retailing (*e.g.* Zara's, Tesco's, Wal-Mart), consumer finance (*e.g.* Capital One, Fidelity), and hospitality (*e.g.* Marriott) have also adopted a more aggressive strategy of business experimentation.

4.3 Share: Digitization makes it possible to share observations, insights and innovations more widely and easily

The Internet and other recent improvements in communications have had a significant effect on scientific and business collaboration. For example, there has been an increasing trend in collaboration among scholars in distance attributable to the decreased communication cost (*e.g.* Griffith *et al.* 2007; Jones *et al.* 2008; Rosenblat and Möbius 2004).

Sharing has also increased within firms, using relational databases, knowledge management systems, intranets, email networks, wikis and a variety of other tools. This has increased the speed at which new findings and insights propagate throughout the firm. The way firms are working to optimize the flow of ideas and information, ideas and collaboration can be compared to the way assembly lines optimized the flow of physical products through factories a century ago (Varian 2008).

Today, the components being combined are made of bits, rather than atoms, which makes it possible to replicate them perfectly and nearly costlessly, and to transport them worldwide almost instantly. Because the process of innovation often relies heavily on the combination and recombination of previous innovations (Weitzman 1998), the broader and deeper pool of ideas and individuals that an innovator can draw on, the more opportunities there are for innovation. As a result, improved sharing has important implications for not just the level of innovation, but also the rate of growth of innovation.

4.4 Replicate: Digitization makes it possible to scale up innovations with greater speed and fidelity

The fourth trend is the ability to scale up innovations rapidly and with unprecedented fidelity. Again, the e-economy leads the way. When Amazon improves its website, the innovation is almost instantaneously replicated in hundreds of millions of its "stores" worldwide – the computer screens of its customers. Similarly, innovations in other digital products like software, music, video and websites can be rapidly replicated and delivered.

High productivity levels and growth of software firms partly result from easy replication of innovations.

The result has been a more Schumpeterian form of competition in these industries, in the sense that new firms are born and quickly supplant the incumbents, resulting in "creative destruction" and renewal. Consider software. Firms that develop better software applications can rapidly grow to dominate the industry, or even create entirely new sectors. At the same time, their dominance is far from assured, with many industry leaders losing their position, or even failing altogether, when competitors or new entrants develop a superior product, or when the dominant platform changes from mainframes, to minicomputers, to personal computers, to the Internet and beyond. The high productivity levels and productivity growth rates of software firms are also consequences of easy replication of innovations.[6]

Today, technology is increasingly making it easier to replicate not just innovative digital products, but also innovative business processes. For instance, when CVS developed an improved prescription drug ordering process for its pharmacies, it embedded the process in an enterprise IT system. Because the process was tightly coupled with technology, CVS could assure that each clerk and pharmacist would

6 For instance, Gandal (1994) and Brynjolfsson and Kemerer (1996) found that the quality-adjusted improvements in spreadsheet software were 10 percent or more per year.

adhere to the new process precisely as it had been designed, increasing overall customer satisfaction scores from 86 to 91. More importantly, the innovation could be rapidly rolled out to over 4,000 physical locations across the country. In effect, the economic impact of this one process innovation was multiplied by 4,000 because it was embedded in technology. This is a marked contrast to the slow and error-prone paper-based or training-oriented procedures that were used for propagating processes a decade ago (McAfee and Brynjolfsson 2008).

ERP systems such as those sold by SAP and Oracle since the mid-1990s have made process replication possible in other industries and for many types of large and mid-sized firms. The geographic reach of enterprise software has been greatly increased by the Internet, which freed companies from having to construct private networks to remote locations. This combination represents a quantum leap forward in firms' abilities to replicate business process innovations widely, rapidly and with high fidelity.

4.5 The emerging sequence – Experiment, Measure, Share and Replicate – is a new kind of R&D

The effects of experimentation, measurement, sharing and replication are amplified when the four are used together.

Important as the trends of experimentation, measurement, sharing and replication are when used separately, their impact is amplified when they are used together. While passive data gathering can be useful, measurement is far more valuable when coupled with conscious, active experimentation and sharing of insights. Likewise, the value of undertaking the experiments themselves is proportionately greater if the organization can capitalize on those experiments in more locations and at greater scale. In combination, these practices constitute a new kind of "R&D" that draws on the strengths of ICT to speed innovation. As flexible, scalable ICT infrastructure makes this approach more widely feasible, the main bottleneck becomes the ability to ask the right questions so that the experiment, measure, share and replicate paradigm can help answer them. This requires both an understanding of business needs and experimental design concepts.

5. Implications for policymakers

As the nature of innovation changes, so too should the institutions and policies that we use to foster innovation.

5.1 Incentives

One of the first policy levers considered by most economists for affecting the pace of innovation is incentives. Patents and other forms of intellectual property rights are enshrined in the constitution in order "to promote the progress of Science and useful Arts." However, stronger IP protection does not necessarily lead to more innovation. Davis (2001) and others have argued that existing forms of IP are not well suited for digital goods and services, and innovations in business processes also appear to be a poor fit. In part, this is because the combinatorial innovation approach common in building digital innovations can be severely hampered when IP law restricts use of the components. Innovations in other fields such as biotech also build heavily on previous contributions. As a result, Williams (2009) finds that the IP rights that Celera obtained when it sequenced parts of the human genome retarded subsequent innovation by as much as 30 percent compared to similar sequences which were placed in the public domain. In some cases, open source projects such as Wikipedia and Linux have been unexpectedly successful. This suggests that institutions that harness non-financial motivations, such as those described by Maslow (1943) may be important.

5.2 Education

Greater investment in education is another common policy recommendation and the measure, experiment, share and replicate paradigm by no means reduces its importance. However, it does put a premium on creativity and the ability to frame questions that are both relevant to the business and amenable to rigorous experimental design and analysis, often using statistical techniques. Education that is overly narrow, however deep, may be less effective in such an environment. Furthermore, if competition becomes more Schumpeterian, firms with a skilled workforce that is flexible enough to quickly adapt to changes will get higher returns on their innovations. Such firms can therefore be expected to invest more in innovation in the first place.

The measure – experiment – share – replicate paradigm strengthens the need for greater investment in education.

5.3 Infrastructure

The benefits of combinatorial innovation are the greater the more distinct components there are to combine. However, the infrastructure that makes such interaction and sharing possible has characteristics of a public good, and there may be underinvestment if it is not subsidized or publicly provided. The American interstate highway system, the Internet and the human genome project are all examples of government-supported infrastructure that fosters innovation by facilitating interconnections.

5.4 Immigration policy

While the global Internet makes it easy to almost instantly transmit gigabytes of data almost anywhere in the world, this does not mean that geography has become irrelevant to innovation. On the contrary, it remains highly uneven, with some areas innovating disproportionately. Innovators benefit from being physically near other innovators so that they can more easily share the types of tacit knowledge and understanding that are difficult or impossible to distil into explicit instructions. Rather than diminishing returns to scientific concentration, the pay-off to each participant often grows with greater concentration, accounting for innovation clusters. Flexible immigration policy can help assure that more of these clusters emerge.

5.5 Flexibility

The waves of "creative destruction" that characterize the increasingly Schumpeterian competition and innovation in the economy lead to the rapid scaling-up and ramping-down of businesses. This requires flexible institutions, labour force and regulatory policies. Antitrust in the e-economy should be less concerned with static market shares and more concerned with potential lock-in and inertia that prevent innovators from supplanting incumbents.

5.6 Rent dissipation *versus* value creation

Not all innovations have equal social value. An innovation that redistributes a dollar of rents does not benefit society as much as an innovation that creates a dollar of new value. In the United States many of the technology investments, and many of the top students, have been devoted to innovating in activities like pricing and bargaining where the private benefits often come largely at the expense of other parties, rather than to science and engineering innovations, where the spillovers are often positive. Policies that enrich or favour the rent-redistributing components of some industries may exacerbate this trend. Philippon and Reshef (2009) found that rents account for 30 percent to 50 percent of the wage differentials between employees in finance compared to engineering since the late 1990s. This has attracted talented individuals from other sectors to the financial sector.[7]

7 According to Goldin and Katz (2008), Harvard graduates working in finance earned almost three times more than their peers, even controlling for their undergraduate performance.

6. Conclusion

Information technology holds promise for increasing the rate of innovation. However, fulfilling this promise will require a transformation by both companies and policymakers that has barely begun. Success in this transition should begin with a clearer understanding of what digitization can do and what it is working in leading firms and sectors.

ICT raises productivity growth by enhancing ICT equipment, catalyzing organizational change, and transforming the innovation process itself.

The explosive improvements in computers and related technologies can raise productivity growth in three ways: directly through technological progress in computers and communication goods, indirectly by catalyzing co-inventions in management and organization, and most recently, by transforming the innovation process itself.

Because innovation ultimately depends on the creation of knowledge, information technology has a unique role in augmenting, if not automating, creativity and discovery. Companies that successfully use technology to improve their measurement, experimentation, sharing and replicating of innovation will be in a position to outcompete their rivals, and gain a growing share of the economic landscape.

The increase in US productivity growth since 1995 is a promising sign. Even more tantalizing is the increase in the performance spread among companies, especially those in ICT-intensive sectors. A large performance spread is *prima facie* evidence that the frontier of practice is far ahead of the mean, and thus a positive sign for future productivity growth. Indeed, it suggest that firms that are currently behind the frontier, whether in the US, Europe, or elsewhere, have great potential benefits ahead of them even if they simply match the current leaders. By many measures, we have a more innovative society than ever before.

Looking to the future, the recent sharp decline in business investment and in particular ICT investment is cause for concern, especially if it inhibits complementary investments. However, it is likely that most businesses are still very far from fully exploiting all the potential complements to 1990s technology, let alone the current ICT capabilities, so there is still room for continued innovation. Even if Moore's Law stopped tomorrow – and it has no signs of slowing down – there is potentially decades' worth of innovation possible just from wringing out the potential of today's ICT.

In some ways, the current downturn contains seeds of hope. Historically, recessions have been a stimulus for innovation and restructuring. The 1930s had more major product innovations than any other decade since the 1850s (Kleinknecht 1987). A majority of Fortune 500 companies were founded during economic downturns (Stangler 2009). Similarly, some companies are using today's challenging economic environment as a rationale for making tough changes that would have been conceptually or politically difficult when they were more profitable. If these changes create more innovative nations and further raise productivity growth, the so-called "Great Recession" may eventually become known as the "Great Restructuring" instead.

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