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ANNEXE 1

The Economic Impact of ICT
SMART N. 2007/0020
December 2008

First Interim Report

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EXECUTIVE SUMMARY[1]

This document represents the First Interim Report of the project "The Economic Impact of ICT", SMART N. 2007/0020.

The main objective of the report is to provide an exhaustive review of the main empirical and theoretical contributions existing on the themes proposed for analysis by the Commission. In so doing, it also provides a critical discussion of the statistical sources used so far to address the various topics which will be analysed in the next part of the tender.

The overall picture arising from the report is can be summarized as follows:

1. The ICT literature has been expanding exponentially over the course of the last 15 years. Over this time period, the consensus over the economic impact of ICT has changed dramatically from a scenario where, as Robert Solow observed, "ICT could be seen anywhere, except in productivity statistics" to one where ICT consistently appears to have strong and significant effects on virtually every aspect of the economy. This effect is evident at all levels of the economy (countries, industries, firms, consumers).

2. As the literature and the available statistical sources have started to grow, it has become apparent that the true economic impact of ICT is much more complex than previously thought. For example, firm studies in this field have revealed the importance of complementary investments in management and organization for the successful implementation of ICT, while consumer studies have illustrated the often diverse effects of the internet on prices across countries and industries. The heterogeneity of the impact of ICT is a key feature distinguishing it from other investments.

3. In spite of the major advances made by the literature over the past few years, there are still noticeable problems and issues which ought to be addressed in further studies. First, the lack of suitable ICT data is still a major obstacle to gain a complete understanding of ICT impacts. Micro level data is missing for several countries and industries, and is mostly limited to hardware technologies. Also, firm-level innovations involving ICT often lack obvious outputs or indicators (e.g. such innovations are often not formally protected by patents or copyright so it is difficult to track them in the data). Secondly, very little is known on the true causal effect of ICT. For example, most of the empirical exercises have documented a positive association between ICT and productivity, but none has so far been able to convincingly tackle the endogeneity issues that might drive this result.

4. Finally, current policy discussions need to clearly delineate the expected role of ICT with regard to identifying market failures. For example, ICT may be a form "knowledge capital" like R&D and could generate knowledge externalities justifying some public intervention. Or it might be that as a form of intangible capital ICT is subject to greater financial constraints due to capital market imperfections (especially in smaller firms). Both the spillovers and financial constraints (and others) stories are less obvious for ICT than for R&D. Therefore the distinctive features of ICT as a form of knowledge capital need to be recognised and understood before outlining policies to encourage its development.

I. ICT IMPACT ON COMPETITIVENESS AND GROWTH

I.1. ICT Impact on Productivity and New Business Models

In this section we provide a brief overview of recent studies that have analyzed the impact of ICT on productivity and economic growth. The section is organized according to the different types of methodologies and data used, starting from the more aggregated ones (growth accounting exercises, usually conducted at the country or industry level), to the most disaggregated (firm level studies).

A detailed analysis of the papers mentioned in this section is provided in Appendix C in the Tables C1, C2 and C3. The summary tables presented here take the same form. Column 1 lists the authors; column 2 the countries and levels of aggregation; column 3 presents the data; and column 4 the measure of ICT used. Columns 5 and 6 respectively present the methods and results.

In the sections immediately below we pay special attention to the two most recent (and arguably complete) growth accounting studies in the literature namely, Jorgenson, Ho and Stiroh (2008) and Van Ark, O'Mahony and Timmer (2008). These two studies summarise many of the research questions and policy issues that dominate discussions of the economic impact of ICT.

A. Macro-Level Growth Accounting Exercises

The productivity impact of ICT has been first analysed using growth accounting techniques. These methods are used to break down the sources of productivity growth across the different inputs used for production, namely labour, materials and physical capital (including ICT). The remaining unexplained component of productivity growth is then typically attributed to improvements in total factor productivity (TFP).

Some of the earliest studies in the field were aimed at understanding the "Solow Paradox": the observation that computers were visible everywhere except in the productivity statistics (Solow 1987). Oliner and Sichel (1994) used a growth accounting framework and careful analysis of BEA and BLS data to show that this paradox was more apparent than real. They concluded that computers could not make a large contribution to aggregate productivity growth in the 1970s and 1980s because they constituted a very small proportion of aggregate US capital stock (about 2 per cent in 1993).

Since then the importance of ICT has grown considerably. Basu *et al.* (2003) estimate that the share of the ICT-producing sector in US value added in 2000 in the private non-farm economy was 5.5 per cent (1.6 per cent computer, 2.31 per cent software and 1.59 per cent communication). This compared to a 3.3 per cent share for the UK in the same year. Although it remains a relatively small share of total value added, ICT makes a substantial contribution to productivity growth because of its fast growth rate and high rate of depreciation (giving its larger revenue share). One of the most remarkable facts has been the rapid growth of labour productivity in the US economy since 1995. This continued through to 2006 despite the high tech crash and the 9/11 terrorist attacks, and reversed a period of slow US productivity growth that set in after the Oil Shocks of the mid-1970s[2]. Many authors point to ICT as having an important role in this acceleration. Practically, this has led to an empirical distinction between ICT-intensive sectors and the rest of the economy. Following the approaches of Stiroh (2002a, 2002b) and Van Ark et al (2008) the ICT-intensive sectors are divided between producing and

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[2] In recent years productivity has slowed down as the financial crisis has worsened.

using sub-sectors. A classification is shown in Table 1 with the ICT-using industries defined as those with above-median flows of ICT investment.

(i) The US Productivity Resurgence

An example of a growth accounting exercise that documents the US experience is given in Table 2 (Jorgensen, Ho and Stiroh 2008). This is the most recent and complete study of its type, summarising the last ten years of growth accounting research on the 1990s productivity resurgence. The authors study US growth from 1959-2006 and posit "two phases" for the post-1995 resurgence in US productivity growth. These phases are 1995-2000 and from 2000 onwards.

The rationale for these phases is evident from the growth accounting results presented in Table 2. Overall growth in output is divided between growth in hours worked and labour productivity (for example, 3.58 = 1.44 + 2.14 in column (1)) with labour productivity then broken down into the standard growth accounting components. The first point to note here is the acceleration of ICT-related capital deepening between the 1973-1995 and 1995-2000 sub-periods. The contribution of ICT capital deepening increased from 0.40 to 1.01, making up two-thirds of the whole capital deepening effect. The TFP contribution of ICT also more than doubled from 0.25 to 0.58 between these two periods. Note that this "TFP contribution of ICT" relates specifically to TFP-growth in the ICT-producing industries and their subsequent accounting contribution to TFP rather than any spillovers to non-ICT industries.

The distinction that Jorgenson et al (2008) make between the 1995-2000 and post-2000 periods are more subtle but is also TFP-related. Both the ICT capital deepening and ICT-related TFP effects slowed down in the post-2000 period while the non-ICT TFP contribution increased from 0.42 to 0.54. These gains outside of the ICT-production sector are suggestive of a "general purpose technology" effect of ICT being felt as it is applied more intensively throughout the economy. That is, time and investment in complementary inputs (such as R&D and organizational capital) have led to gains outside of the narrowly defined ICT sector. However, this is by necessity a cautious conclusion with Jorgenson et al (2008) noting alternative explanations such as cyclical movements (also advanced by Gordon (2003)) and an increase in competitive pressures (Oliner et al 2007).

More generally, an important question is what mechanisms have driven the ICT-led resurgence in productivity noted above? In the growth accounting framework the model is relatively simple: there has been rapid technological progress in the ICT producing sectors. In particular, the technology cycle for semi-conductors appears to have speeded up after 1994 and this led to a very rapid fall in quality-adjusted prices for ICT goods (Jorgenson 2001). This was reflected in TFP growth in the ICT producing sectors and ICT capital deepening in other sectors (that is, since the user cost of ICT capital had fallen there was substitution into IT capital and away from other factors of production). Both elements contributed to productivity growth, but the underlying factor is rapidly falling ICT prices.

In a provocative series of articles, Gordon (2000, 2003) took issue with the view that ICT use played an important role in US productivity growth after 1995. He is sceptical about the ability ICT to affect productivity growth and in Gordon (2000); he claims that outside the ICT producing sector, productivity growth in the US economy was entirely cyclical. Despite the inherent problems of knowing exactly how to correct for the cycle, this view had some plausibility for the late 1990s. But this view seemed very implausible by the end of 2005. The US economy had suffered some cyclical downturns with the stock market crash of 2000, 9/11, the Iraq War, high

oil prices and other shocks but productivity growth continued to power ahead. Furthermore, Stiroh (2002a) produced econometric evidence based on industry data that there was significant productivity growth in the intensive ICT-using sectors, even after controlling for macroeconomic shocks.

(ii) Comparing US and European Productivity

The second major theme of the recent growth accounting literature relates to the contrast between US and European performance. Again, the recent study by Van Ark et al (2008) summarises a decade of research findings on this topic. The US-EU productivity differential has evolved in three phases that can be charted as follows:

- The **first phase** from 1950-1973 was a period of catch-up where EU GDP per capita grew more quickly – 5.3% per year versus 2.5 % for the US. (See Table 3). Van Ark et al (2008) identify technology imitation and the influence of new post-war institutions (particularly those related to wage bargaining) as the key factors behind this phase of catching-up.

- The **second phase** is typically identified as the 1973-1995 period and was characterised by a slower rate of catch-up which is attributed to slower employment growth and a subsequent increase in capital intensity.

- The **final phase** from 1995-2006 was marked by a significant slowdown in EU productivity with average growth in GDP per capita running at 1.5% for the EU and 2.3% for the US. A breakdown of labour productivity growth differences by country and sector is given in Table 4. This shows that the productivity gap is greatest in two areas: ICT production and market services. The result for market services is the most striking with an EU growth rate of 0.5% versus a US rate of 1.8%. Although financial services were part of the market services experiencing impressive productivity growth, the results are not driven only by this sector. Retail and wholesale trade posted very rapid productivity growth throughout this period. However, these figures are also suggestive of important differences within the EU. The UK's growth rate in market services is 1.6%, which is closely comparable to the US and in line with perceptions of the UK's economic similarities to the US in terms of labour and product market regulation.

There has been much discussion over this productivity difference between the US and Europe, but no definitive consensus has emerged. Some authors claim it is simply a matter of time before Europe resumes the catching up process (Blanchard 2004) while others point to more long-term structural problems in Europe such as over-regulated labour and product markets (Gust and Marquez 2004). Basu *et al.* (2003) examine the differences between the US and UK. Similar to Van Ark et al (2008) they find that the UK did *not* experience productivity acceleration 1995-2000 relative to 1990-1995.[3] They found the US-UK difference difficult to account for, but argued that the UK is likely to catch up because of its later investment in complementary organizational capital. Additional results at the macro level are summarized in Table 2.

B. Industry level Studies

The industry-level studies we discuss in this section are distinguished by their methods. That is, they employ mainly econometric methods in contrast to the growth accounting tools used in the

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[3] Oulton (2002) also shows that the contribution of ICT to UK productivity growth increased from 13.5% in total growth in 1979-1989 to 21% in 1989-1998. This is less than the US experience, but greater than the European average.

literature discussed immediately above. Early industry studies (for example, Berndt and Morrison 1995) found no significant relationship between ICT and productivity. Industry level studies using more recent data, found significant returns to IT capital over the 1987-2000 period, based on a study of 58 industries (Stiroh 2004). Stiroh's study looked at IT capital as a whole, and at the individual sub-components (computers and telecom). Although Stiroh (2002a) found there was faster productivity growth in the ICT intensive sectors post 1995, Stiroh's (2004) later study found no evidence that the coefficients on IT capital rose in 1996-2000 (compared to 1987-1995). The absence of effects that marked earlier studies may be due less to the time period analysed and more to the combination of noisier data and ICT being a much smaller proportion of total capital.

However, when Stiroh (2004) looks at econometric estimators that attempt to control for fixed effects (for example, through differencing the data) and/or endogeneity (for example, through the GMM panel data estimation method) there were few significant results. This may be due to genuine misspecification and the absence of an ICT effect or, more plausibly, because the industry-level data are still too coarse for some of the more sophisticated econometric approaches to be effectively applied.

Most of the other studies in the industry level literature focus on TFP growth equations of the type discussed above in the section above. Overall, the results mirror Stiroh's findings. The ICT coefficients tend to be generally insignificant, unstable across time, and across countries (for example, Basu *et al.* 2003). The TFP regressions have the problems of the aggregate industry data and the problems discussed in the section on TFP approaches, that ICT is included on the left hand-side and the right hand-side of the estimating equations. The results at industry level (or below) are summarized in Table 3.

C. Firm level studies

Given concerns about aggregation and other biases attention has shifted to the more micro-level. The results at firm level (or below) are summarized in Table C3.

There are four prominent features of the firm-level literature that can be summarised as follows:

- First, most studies do reveal a positive and significant association of ICT with productivity. This is reassuring as many were undertaken in response to the Solow paradox, which suggested there was no productivity impact from IT.

- Second, the magnitude of the ICT coefficients is much larger than might be expected from the standard neoclassical assumptions underlying the growth accounting framework. A well-known example here is Brynjolfsson and Hitt (2003) which examines large publicly traded US firms. The main explanation offered for this finding relates to the presence of complementary organizational capital. That is, the measures of ICT used in these studies may be capturing the effect of ICT as well as other complementary inputs such as organizational structures, efficient management practices or other advanced, non-ICT production technologies. As a result, the calculated return to ICT will be higher than if ICT was measured in isolation. Econometrically, this is an endogeneity problem that implies the need to develop strategies (such as instrumental variable techniques) to obtain causal estimates of ICT's impact.

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- Third, the explanation that the high magnitudes are due to organizational capital does get some support in the firm-level literature. This includes the study by Bresnahan, Brynjolfsson, and Hitt (2002) who conducted a survey containing explicit questions on decentralization within firms[4]. Black and Lynch (2001, 2004) and Caroli and Van Reenen (2001) do not find support for interactions between ICT and organization, but they have less sophisticated measures of ICT capital than Brynjolfsson and his colleagues. Bloom, Sadun, and Van Reenen (2008) find some support for the organizational capital hypothesis as they find much higher returns for the ICT in US multinationals compared to non-multinationals than between statistically similar establishments in the UK. Furthermore, their work establishes that important interaction effects between ICT and aspects of the organization (such as "people management" practices[5]) in predicting productivity. US (and other) multinationals transplant such practices abroad and this fosters higher returns to ICT.

- Finally, there is a very wide range of estimates of the elasticity of output with respect to IT capital. The Stiroh (2004) meta-study is very useful for comparing the sub-set of studies considered here. He finds that the mean of the estimates across studies is about 0.05, which is well above the share of the ICT stock in revenue as noted above. In simple terms this elasticity suggests that for a 10% increase in ICT inputs there is a 0.5% increase in output[6]. However, the estimates range from an upper end of over 25 per cent to minus 6 per cent. This wide variation is in part driven by methodological choice, but also is strongly suggestive of heterogeneity in the ICT coefficient by country, industry, and type of firm. Bloom, Sadun, and Van Reenen's (2008) findings of systematically different returns by ownership type and industry corroborate this. In particular they find that US firms receive a higher return from ICT and this higher return is driven by the sectors that intensively use ICT (the same sectors underlying the US productivity acceleration highlighted in section A).

D. Problems and Future Directions

The literature on the link between ICT and productivity still suffers from some significant problems. These problems can be summarised as follows:

- None of the literature has produced convincing evidence of a **causal impact on ICT** on productivity for example, by analyzing a natural experiment. Even the more sophisticated studies rely on standard panel data techniques for dealing with endogeneity[7]. In the economics of education there are some studies examining the impact of computers on school productivity, which use policy variation to try to address the endogeneity issue. Angrist and Lavy (2002) in a study of learning in Israeli schools, find that treating computers as endogenous shows that there may actually be a negative effect from ICT. Machin, McNally, and Silva (2006), however, did find some positive effects of ICT in their study of English schools.

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[4] This includes decentralization of control over task allocation and the pace of work to employees and greater teamwork.
[5] This incorporates promotions, hiring and firing and reward systems (see Bloom and Van Reenen, 2007) for a detailed description.
[6] The elasticity of ICT in the production is equal to the rate of return multiplied by the share of ICT capital in output. Therefore given the elasticity of 0.05, any ICT share less than this will give a very high rate of return.
[7] For a survey of such techniques see inter alia Wooldridge (2003). A popular GMM method is to use assumptions over the properties of serial correlation in the error term to generate moments that can be used in estimation (see Blundell and Bond, 2000). In other words, to exploit the idea that although current ICT may be endogenously determined, lagged ICT can be taken as weakly exogenous.

- Another area where more work is needed is specification of the types of **complementary organizational practices** in more detail. What are they? What determines their distribution? Why do some firms appear to be better than others at introducing these organizational practices? Is this the explanation for differences between the US and other OECD countries?

- On a more mundane level, the micro studies have focused more on hardware than **software** because of the lack of good data. Using software as well as hardware, and building in communications, has been done much more systematically at the macro than at the micro level. This is important because unmeasured software may be a fundamental reason for different returns to hardware.

- Another lacuna exists in establishing a **solid link between micro and macro**. For example, micro studies may tend to overestimate the benefits of productivity growth if the impact of ICT mainly comes from redistributing the quasi-rents between oligopolistic firms (for example, in finance). This would not occur of we had 'true' productivity measures, but the dependent variable is usually deflated sales divided by labour which mixes productivity and the mark-up (e.g. de Loecker, 2007). Some element of the mark-up is legitimate product quality, but others may simply be market power from other sources. Finally, the most prominent studies are still US based. There is a need for more cross-country comparisons at the micro level to examine why there may be differential returns for similar firms in different countries.

The approaches that will be pursued in the empirical analysis that will form the next part of this tender will offer some answers to the above problems. These approaches include:

- Firstly, the development of a large cross-country firm-level dataset maximises the scope for developing causal estimates of the impact of ICT. To be clear, in such a context there is more variation in ICT adoption that may due to exogenous country, regional and institutional factors. This exogenous variation in adoption can then be used as an instrumental variable for ICT in the production function.

- Secondly, the CEP's International Management Survey (IMS) contains detailed information on management practices and organizational structure. This data therefore provides the information needed to address detailed features of the relationship between ICT, management practices and organization. Finally, the link between micro and macro can be developed with large scale microdata. A key advantage with such data is that it makes it possible to break down specific sectors across countries. For example, the performance of firms in market services can be separately analysed to see how the productivity performance of firms varies across the distribution[8],

I.2 ICT, Clusters and Network Externalities

In business and policy circles, the commonly held view is that rapid advances in ICT should act as a dispersion force spreading economic activity more evenly across space. Cheap communication over the Internet should make it easy to collaborate over wider geographical distances, for example. However, contrary to the prominent claims of a "death of distance", economic theory remains ambiguous about the effect of ICT on spatial concentration. Recent empirical evidence is similarly mixed. For example, the expansion of telephone lines appears to

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[8] In particular, aggregate productivity comparisons may be driven by particular parts of the distribution (for example, "long tails" of under-performing firms).

have dispersed activity from larger to smaller cities. In contrast, work on the internet points to the possibility of a complementarity between digital communication and the economic forces that attract firms to urban locations. We briefly review recent theoretical and empirical contributions on this topic.

A. Theory of Clustering

The spatial concentration of economic activity occurs because physical distance makes transport and communication more difficult so that interacting across space is costly. These `transaction costs' mean that physical proximity provides benefits. Economists often refer to these as `agglomeration benefits' or `agglomeration economies'. Of course, physical proximity also brings with it costs, as individuals and organisations compete for scare local resources. Economists usually refer to these as `dispersion forces' or sometimes, particularly in urban settings, as `congestion costs'. In economic thought, the distribution of activity across space results from the trade off between these agglomeration economies and dispersion forces. Changes in transaction costs as the result, for example, of improvements in ICT will change the balance between these two opposing forces and hence, change the spatial distribution of economic activity.

If *all* of these transaction costs were *zero* then, economic activity would, indeed, spread evenly over space. This is the outcome envisaged in the popular writings that talk of a "borderless world" (Ohmae, 1990); the "death of distance" (Cairncross, 1997; 2001), or of a "flat world" (Friedman, 2005). In different ways, these authors argue that drastically falling trade and communication costs have made human interactions less dependent on physical proximity with the result that economic activity is spreading out over space and will continue to do so. The problem with these predictions is that while transaction costs remain positive, *falling* transaction costs affect both agglomeration *and* dispersion forces and the overall effect on the spatial distribution of economic activity will depend on which of these falls fastest. The overall effect is thus ambiguous and formal economic models suggest that *increasing* spatial concentration as transaction costs fall is just as conceivable as the spreading out that is so widely predicted in popular discourse.

This ambiguity is one of the crucial theoretical predications to emerge from the so-called New Economic Geography which developed following Krugman's pioneering work (Krugman, 1991). Models in this tradition assume imperfectly competitive firms produce differentiated products subject to increasing returns to scale. Because transport of goods between markets is costly locating in larger (core) markets makes it easy for firms to sell to their customers but at the cost of increased competition from other firms located there for the same reason. Lowering transport costs between markets reduces the benefits of locating near to customers but it also increases competition everywhere. That is, falling transport costs reduce both the benefit (relatively better access to customers) and the cost (relatively higher competition) of locating in the larger market. What happens to overall spatial concentration depends on which effect dominates and the overall effect is ambiguous.

This prediction of the ambiguous effects of reducing transport costs carries over to theoretical models where ICT predominantly reduces the cost of transporting intermediate or final goods across space. What about the effects, however, when we focus on the role that ICT plays in facilitating communication and the transmission of information? Again, economic theory tells us that the affect can be ambiguous. For example, in slightly different frameworks Leamer and Storper (2001) and Duranton and Puga (2005) show that a fall in communication costs can have

complex effects on the spatial organisation of production within firms. In these papers, improved ICT reduces the costs of communication allowing for a greater segmentation of the stages of production. This, in turn leads to a higher demand for complex managerial services and innovative activities. Because these tasks are potentially subject to strong agglomeration effects (because of, for example, the importance of face-to-face contact), managerial or "headquarters" functions can become increasingly spatially concentrated in metropolitan centres even while manufacturing activities move out of cities. The overall effect on spatial concentration of this "functional specialisation" (different types of activity in different places), and hence on employment and income, is once again ambiguous.

Gaspar and Glaeser (1998) take a different approach, but reach a similar conclusion. Their focus is on the way in which ICT directly affects interactions between individuals. In particular, they study how ICT might directly change agglomeration economies arising from the need for face-to-face interaction. They emphasize that an increase in the ease of communicating across space can have two opposite effects on the overall demand for face-to-face interaction. The first is a substitution effect – the availability of ICT makes it easier to communicate without the need for personal meetings. Working on its own this would mean that better ICT reduced the demand for physical proximity. But going against this is a second complementary effect which arises from the fact that as the cost of maintaining any given relationship goes down (because ICT makes it easier to communicate) people will be able to support more relationships. The overall impact on the demand for face to face interactions is ambiguous and so, once again, is the overall effect on spatial concentration.

To summarise, this brief review of the main theoretical contributions on the impact of ICT on the spatial distribution of economic activity highlights the fact that, contrary to popular opinion, better ICT can lead to either more or less spatial concentration. Empirical work will be needed to help distinguish between these two possibilities, and it is to this that we now turn.

B. Empirical Evidence on Clustering

When it comes to the real world impact of ICT on spatial concentration, anecdotes abound and there is a large amount of case study evidence but there is surprisingly little systematic empirical evidence covering either a wide range of locations, or activities, or both. The most extensive evidence relates to the spatial distribution of ICT infrastructure. This partly reflects an increasing political interest in the notion of the "digital divide" (Norris, 2001) as well as the availability of data. The geographical element of this broader sociological debate considers both the international and intra-national concentration of ICT infrastructure and digital access. Chinn and Fairlie (2004) provide an international example using data for a sample of more than 160 countries. Townsend and Moss (2000) are an early example on the sub-national concentration of ICT infrastructure and their uneven rates of expansion. Looking at the case of the US internet backbone network, they argue that, perhaps unsurprisingly, the physical infrastructure of the internet is subject to an inherent metropolitan bias. Evidence presented in Wang, Lai and Sui (2003) supports this. They develop a GIS approach to map the internet in terms of links and bilateral access propensities, and find that physical distance is one of the major determinants of 'digital proximity' between US higher education websites. Once again, this evidence points against a simple 'death of distance' story by showing that the provision of the infrastructure itself is highly spatially concentrated.

Turning from ICT infrastructure to its effects, a small number of studies have tried to systematically consider the way in which ICT affects communications across space. Gaspar and

Glaeser (1998) present descriptive evidence in favour of an overall positive relationship between the spread of telephony and the demand for urban face-to-face contact by looking at US time trends of the relationship between call propensities and geographical distance, business travel, and academic co authorship. Referring back to the discussion above, the complementary effect of ICT on the number of relationships appears to outweigh the substitution effect on the number of interactions for any given relationship. In line with this, Charlot and Duranton (2006), investigating French survey data on workplace communications practices, find no evidence for an increase of inter-firm communication across urban boundaries between 1987-97.

A series of recent papers have taken up the question that Gaspar and Glaeser (1998) raise with respect to telephony by seeking to answer the question of whether or not the expansion of the internet is a complement or a substitute for localised urban spillovers such as face-to-face contact. Kolko (1999) addresses this question empirically by looking at the relationship between city size and internet density. The hypothesis is that after controlling for a set of alternative city characteristics (including education, income, industry composition, city age, infrastructure quality, etc.), a substitute relationship should result in a negative relationship between city size and internet density, while a composite relationship should result in a positive relationship. In line with the results on telephony, Kolko finds evidence in support of a positive relationship.

Sinai and Waldvogel (2004) have access to a richer data set on internet usage which allows them to control for the extent of local subject content. They find that larger cities have a disproportionate amount of local content available on the internet which should attract a higher internet usage density in its own right. After controlling for local content, they find that internet usage propensity is negatively related to city size. Despite this evidence for a partial substitution effect, the authors emphasize that the overall relationship between internet density and city size is still positive because internet density also partly explains the availability of local content.

Forman, Goldfarb and Greenstein (2005) switch focus from the consumer side of internet usage to firm communication. After controlling for industry effects, they find that establishments in smaller cities are more likely to use simple digital communication services, such as email, to contact other firms. On the other hand, they find that larger cities are more likely to have more sophisticated channels of digital communication, such as e-commerce, B2B portals, or inter-branch intranets. They find that the overall effect of the internet is to favour communication in larger cities, driven both by industry composition and the higher propensity to have more sophisticated digital communication systems in place.

So far, we have reviewed evidence on the spatial concentration of ICT infrastructure and the impact that ICT has directly on communications. What are the implications of both of these for the spatial concentration of economic activity? We have very little systematic evidence.

Ionnides et al. (2008) look directly at the effect of ICT on spatial concentration and the relative sizes of cities in particular. Using cross- country data their regression results suggest that the expansion of telephone lines over the second half of the 20th century has led to increased dispersion of economic activity across urban systems within countries. Evidence on the impact of the internet is suggestive of a similar effect, although the authors note that, for a number of reasons, these results need to be interpreted with more caution.

A very small number of related studies focus specifically on the argument that the ICT revolution affects urban structure through its impact on the re-organisation of production within firms. Their findings are in line with the original contribution by Duranton and Puga (2005) who document an

increasing trend towards functional divisions between US metropolitan areas over the 2nd half of the 20th century. In line with the theoretical predictions discussed above, managerial tasks are increasingly concentrated in diverse metropolitan environments while production tasks tend to be located in smaller more uniform cities.

A more general issue in the literature is that of the "digital divide" in the usage and access to ICT resources at a number of levels, including space. We also discuss this issue at the level of households and consumers later in Section I.5. As Cigan (2002) notes the digital divide affects the opportunities of individuals and businesses to take advantage of the potential gains that accrue to ICT in terms of lower search costs, ICT skills development and the facilitation of efficient customer and supplier relationships. The review by Cigan (2002) also highlights the role of internet access pricing regimes in affecting the incidence of internet usage demand across countries. This opens up a wider issue of the demographic, economic and institutional determinants of the digital divide across regions and countries. The paper by Cheryan et al (2005) conducts a microdata-based analysis of the digital divide in the UK. In that study the authors control for a range of firm and region characteristics (age, size, listed status, 4-digit industry, regional skills) in order to explain regional differences in ICT intensity. They find that even after controlling for this range of determinants the London and East Anglia regions still display a 12-17% higher ICT intensity than other UK regions. The research agenda for this type of analysis of the digital divide can therefore be envisaged as a threefold process of (i) extending the countries and regions used in a microdata analysis; (ii) considering both a wider range of technologies (ie: left-hand side variables) and determinants (ie: right-hand side variables, in particular possible policy-related variables); and (iii) offering a clear breakdown the role of observable and unobservable factors in determining the digital divide.

Finally, there is an ongoing discussion of the implications of non-spatial "virtual" clustering through the use of ICT (Romano et al 2001; Traxler and Luger 2001). Following the arguments of Romano et al (2001) such virtual clusters involve the substitution of geographic proximity with organisational proximity. This "organisational" criterion is based around the customer and supplier relationships of firms. Romano et al's (2001) case study of 29 virtual clusters identifies software tools such supply chain management (SCM) and customer relationship management (CRM) as key enablers of virtual clustering. Their diverse examples of virtual clustering include the activities of a publisher (which organises 150 dispersed photographers using SCM) and a microchip manufacturer (which co-ordinates design and production activities across countries). However, while it seems that virtual clustering is common so far the literature on the topic has not managed to "aggregate up" these individual cases into trends with clearly defined economic impacts.

To summarise, while there is a relatively large literature on the spatial distribution of ICT infrastructure, there is much less on the effect of ICT on the geography of communication and almost nothing on the eventual impact on the spatial concentration of economic activity. What evidence we do have suggests that ICT may be leading to a spreading out of overall activity across cities, but with different functions becoming increasingly spatially concentrated within that overall distribution.

I.3 Drivers and Obstacles to ICT uptake

The topic of the drivers and obstacles of ICT uptake is prefigured in the general literature on technological diffusion. The modern literature on technology diffusion was inaugurated by Griliches' (1957) agricultural study and is comprehensively summarised in Geroski (2000). The

review we provide below first puts forward a general model of technology diffusion (based on Karshenas and Stoneman's (1993) study of computer and numerically controlled machines) and then outlines the results from a number of empirical studies of ICT diffusion in Europe and the United States. This review focuses on key studies that use detailed firm-level microdata and draws conclusions for future research on this basis.

A. Models of Technology Adoption and Diffusion

Firstly, in terms of definitions **adoption** refers to individual-level decisions to use a new technology while **diffusion** describes the aggregation of those decisions across a number of firms (Forman and Goldfarb 2006). At the most basic level technological adoption is determined by a comparison of costs and benefits by potential individual users. That is, a given firm will choose to adopt or intensify its use of a technology by weighing up the economic costs and benefits of that technology. This can be most simply described by the following equation:

$$NB(x_i, z_i, t) = B(x_i, z_i, t) - C(x_i, z_i, t) > 0$$

Where x_i represents firm-level factors that influence the costs and benefits of adoption (such as firm size, workforce skills or management practices) while z_i represents industry and region level factors (for example, levels of product market competition, unionisation, exposure to international trade, or regional infrastructure). Common macroeconomic influences are in time, t.

The basic framework is elaborated in more detail by Karshenas and Stoneman (1993). They classify the different factors driving adoption in terms of rank, stock and order effects. These effects can be summarised as follows:

- Rank Effects: These effects refer to how the inherent characteristics of firms affect their decision to adopt. The standard example is firm size which obviously has a great influence on the potential economies of scale available to a firm that introducing a new technology. That is, larger firms have greater scope to spread the sunk costs of technological adoption across higher levels of production.
- Stock Effects: In this case, the benefits of adoption are endogenous to other firms' decisions. For example, the rents that can be obtained by adopting a technology may be dissipated as more and more firms acquire it.
- Order Effects: This final set of effects relate to how the order of adoption may affect a firms potential costs and benefits. For example, early adopters may be in a position to reap higher returns by being the first firm(s) to use the technology. Practically, this can be through the capture of complementary assets that are needed to fully exploit the technology (such as key geographic sites).

As Forman and Goldfarb (2006) point out the stock and order effects are examples of negative network externalities. In contrast to these effects a critical mass of adopting firms may be required to maximise returns to the new technology, thereby creating positive network externalities.

B. The Literature on ICT Adoption and Diffusion

The current research on the adoption of ICT is at its most comprehensive when dealing with the uptake of various components of ICT (particularly internet technologies) in the United States, with some recent work on individual European countries. We summarise a large range of

studies in Table 5. This represents a selection of key studies that use microdata across the US and Europe.

(i) ICT Uptake in the United States

The US literature has concentrated in particular on the uptake of internet related technologies and has been led by studies that use commercial or marketing microdata on IT investments, particularly from the company Harte-Hanks. Panel A of Table 5 highlights three representative studies by the team of Forman, Goldfarb and Greenstein, as well as the recent study by Beaudry, Doms and Lewis (2006).

The study by Forman, Goldfarb and Greenstein (2003) looks at the industry-level distribution of internet usage in the 1998-2000 period. It distinguishes between "basic" and "enhanced" usage where enhanced usage relates to investments in major e-commerce applications. The FGG (2003) study finds that while basic usage had reached saturation levels by 2000 there was more dispersion evident in terms of the enhanced level. This dispersion generally reflected pre-existing patterns of IT usage except for some new leading industries with high logistical needs (i.e.: transportation and warehousing).

The other two studies by FFG (2005, 2007) discuss the link between industry and regional characteristics in determining adoption. Specifically, FFG (2005) adds a distinction between urban and rural adoption to the earlier framework of basic-enhanced usage. This study finds that the adoption of basic technologies is more likely for rurally-based firms, even when controlling for industry composition. However, urban locations are still more likely to adopt frontier internet technologies, particularly those related to the creation of within-firm networks.

Finally, the FFG (2007) paper looks at how "co-invention" requirements affect firms' decision to adopt the ICT. Specifically, co-invention relates to the sophistication of a firms deployment of ICT, that is, customization or value-adding using complementary resources. The central question of FFG (2007) is whether firms located in cities are able to access these complementary more easily (for example through outsourcing). The measure of internal resources used is the number of programmers and it is found that firms outside large cities use more resources compared to urban-based firms.

One of the key findings in the ICT literature is the importance of skills and human capital. There is substantial evidence that ICT and human capital are complements (see Bond and Van Reenen, 2007, for a survey)[9]. This implies that diffusion of ICT should be strongly influenced by increases of skills. The paper by Beaudry, Doms and Lewis (2006) provides an analysis of city-level ICT adoption pattern across the US between 1990 and 2000. They nest their analysis within a model of endogenous technological adoption which features a strong role for the relative supply of skills. The main prediction of their model is that firms with high relative supplies of skills (and hence lower relative wages) were more likely to adopt ICT than other cities. This prediction is confirmed in their data, along with the related prediction that these cities would also be experience stronger relative wage growth as a result of more intensive adoption. They have some plausible instrumental variables for skill supply such as immigration shocks, which makes this one of the more important studies.

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[9] The study of ICT, organization and productivity in Bresnahan, Brynjolfsson and Hitt (2003) finds that the output of firms with both high levels of ICT and high numbers of skilled workers is 4% higher than firms with comparable levels of labour and capital inputs. It is also the case with this paper that the combined, interacted effect of ICT and skills is actually larger than the linear effects of these two variables.

(ii) ICT Uptake in Europe

Compared to the US, the European literature on ICT adoption has featured very few firm-level or cross-country studies. The studies by Hollenstein (2004) and Battisti et al (2005) analyse microdata for Switzerland and the UK. Hollenstein's (2004) paper looks at Switzerland exclusively and finds that firm size is an influential determinant of adoption up to the 200 employee threshold. Swiss and UK adoption patterns are then contrasted in Battisti et al (2005) where organisational change variables are found to be more important for adoption in the UK.

However, the European firm-level studies of Kretschmer (2004, 2006) feature an alternative focus on the detailed components of ICT adoption. Specifically these studies look at how technologies such as Enterprise Resource Planning (ERP), Database Management Systems (DBMS) and Operating Systems (OS). This leads to some interesting findings with Kretschmer (2004) showing that larger firms are more likely to adopt specialist or niche OS. The later Kretschmer (2007) paper then finds internal complementarities in the adoption of DBMS and ERP programmes. Both of these studies use Harte-Hanks Market Intelligence microdata for the UK from 2000-2004.

(iii) The Role of Labour and Product Market Regulation

A key policy issue for the study of ICT diffusion is the role of labour and product market regulation. This general issue has been heavily studied by the OECD with the development of special country-level indicators of labour market regulation (Nicoletti et al 2000) as well as consistent sector-level information on product market regulation (Conway et al 2005). While the relationship between these types of indicators and general economic outcomes (productivity, output, unemployment) has been the subject of a large literature there has been less discussion of the impact of regulation on technology diffusion. However, the studies by Bouckaert, van Dijk and Verboven (2008); Denni and Gruber (2005) and Wallsten (2006) offer a detailed discussion of product market regulation and the diffusion of broadband. The Bouckaert et al (2008) study is especially comprehensive in providing an econometric analysis of the determinants of broadband diffusion across the OECD, with the following findings:

- Large effects of inter-platform competition on overall broadband penetration. Inter-platform competition is essentially represented by the presence of alternative delivery platforms such as DSL and cable. Bouckaert et al (2008) finds that countries with roughly equal inter-platform market shares have 10% higher broadband penetration rates.

- In contrast, facilities-based intra-platform competition[10] does not have a significant effect on broadband penetration. Service-based intra-platform competition[11] is actually associated with a small and significant negative effect on overall penetration. This could be an indication of the "splintering effect" (Kretschmer, 2008), which describes the decrease in consumers' adoption incentives when faced with multiple similar options with network effects.

- These trends are also apparent in Bouckaert et al's (2008) more detailed results for broadband penetration across Belgian regions. Again, using regional data the authors find that areas where inter-platform competition was encouraged (such as Flanders)

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[10] This describes a situation where, for example, two operators offer DSL services on their own infrastructure.
[11] An example of this would be two firms offering services (i.e. bandwidth) using the same infrastructure, i.e. the same physical network.

exhibit higher penetration rates than regions where service based inter-platform was emphasized.

- In terms of cross-country factors Bouckaert et al (2008) find that a $1000 USD increase in GDP is associated with a 0.9% increase in the broadband penetration rate. Similarly, a 10% increase in PC intensity (i.e.: number of PCs per person) is associated with a 2% increase in broadband rates and population density is also associated with higher penetration (an increase of 1000 people per square kilometre is related to a 3% increase in broadband penetration).

As we point out above there is an extensive literature discussing the economic implications of labour market regulation for European productivity (e.g. Blanchard 2004). Arguably, this literature offers two countervailing predictions for the impact of labour and product market regulation on technology adoption. For example, a key insight of these studies is that labour regulation in Europe has tended to *encourage* capital deepening because of the higher cost of labour (e.g. a high level of the minimum wage). Insofar that ICT is an element of capital then it could be expected that its diffusion in Europe should be higher than the US. There is an opposite countervailing effect, however. It was argued above that high returns for ICT require significant adjustment of the firm's organization (as argued above) and often the reduction in the number of unskilled workers. If labour regulations (e.g. high firing costs) make such adjustment difficult, then firms will be reluctant to increase ICT in the first place. This is the argument in Gust and Marquez (2004) formalized in Bloom, Sadun and Van Reenen (2007). Both these papers (Gust and Marquez at the macro level and Bloom et al. at the micro level) find evidence that the higher level of labour market regulation in Europe may be a factor in lower ICT investment than in the US. Naturally, labour market regulations are correlated with other factors (such as product market regulation), so demonstrating a causal relationship is difficult, but this is suggestive evidence of why the EU has been lagging behind the US in ICT.

C. ICT and Network Effects

Information and Communication Technologies (ICTs) are subject to network effects, or positive consumption externalities. As discussed above, these network effects can have major impacts on the decision to adopt various technologies and therefore merit close consideration. We begin with a short definition of the two types of network effects relevant to ICT and then provide some ICT-related examples.

(i) Defining Network Effects

Many communication technologies are only useful if the number of potential communication partners is sufficiently large (Arthur, 1989). That is, the utility derived from the consumption of network goods is affected by the number of other people using similar or compatible products and utility increases when there are more users to communicate with. This is what we call a direct network effect. Indirect network effects describe the situation where utility depends on the availability of complementary goods which in turn depends on the number of potential buyers. Indirect network effects are often found in more complex, modular products, for example the software running on a computer which consists (at least) of an operating system and applications software.

The utility function for a network good typically consists of two components, the **standalone value** of the network good (a_i) and the **network effect** which depends on the number of users of the network (n_i) and the strength of the network effect (α). Most academic (theoretical and empirical) work uses a simple additive specification, for example: $u_i = a_i + n_i^{\alpha}$ (Kretschmer and Schneider, 2008). Depending on the network effect strength α, we get increasing, decreasing or constant marginal returns of network size, as shown in Figure 1. While much of the theoretical literature some variant of Metcalfe's Law, in which the utility of a network increases nonlinearly in network size (i.e. $\alpha > 1$) or constant marginal returns to network size ($\alpha = 1$), most empirical work (e.g. Grajek, 2007, Ohashi, 2003) and some theoretical work (Birke and Swann, 2006) find that marginal returns to network size are decreasing, i.e. $\alpha < 1$. This has important implications for the likely long-term market structure and the benefits to having a large network as $\alpha < 1$ will leave room for small niche networks appealing to a small fraction of consumers, while the network effect that is lost from niche users not joining the larger network is unlikely to be large given the decreasing marginal returns to network size.

(ii) ICT-Related Network Effects

Most ICTs will have elements of both direct and indirect network effects. Telephony for example displays direct network effects through the communication possibilities with a large network of users, while there are indirect network effects through the provision of infrastructure that will only be profitable if there are enough potential consumers to justify the investment. Previous studies have found that both direct and indirect network effects exist at the level of adoption of mobile telephony (Koski and Kretschmer, 2005; Gruber and Verboven, 2001) and across different technological generations such as fixed-line and mobile telephony (Barros and Cadima, 2002), while network effects appear to be fairly limited across different networks of the same generation (Grajek, 2007) and pertaining to actual (post-adoption) usage intensity (Grajek and Kretschmer, 2009).

Similarly, computer software is typically subject to direct network effects since within firms, employees can exchange data etc. if they use the same standard. In that sense, the notion that firms should decide centrally on a single software standard to maximize the network benefits from using a joint software standard is intuitive. However, it has been shown in previous theoretical and empirical work that this effect is not complete and can be counteracted by the need for variety (Farrell and Saloner, 1986; Kretschmer, 2004) or the existence of only limited network benefits even within the firm (Dosi and Bassanini, 1998). In an empirical study, Kretschmer (2004) finds that a sizable proportion of UK firms (approximately 25%) do not even standardize on a single PC Operating Systems despite significant network effects. A similar result is found in Kretschmer (2006) for Database Management Systems (DBMS), where a tendency to use multiple DBMS within the firm is documented. In both studies, however, an important finding is that there are significant benefits from using products by the same vendor, which suggests that compatibility with other software in the firm plays some role in the decision to adopt a new piece of software. Along similar lines, computer software is also subject to indirect network effects because different products are required to work together either through the exchange of files and data across applications from a technological standpoint or through the use of a common or similar user interface across applications from a user's point of view. Finally, different applications may fulfill different, but related tasks and may therefore be complementary to each other. Indirect network effects in computer software have been identified by several authors, including Gandal (1994), Brynjolfsson and Kemerer (1996), Kretschmer (2006), and Gamharter and Kretschmer (2008).

The existence of significant network effect in ICT has several implications for the market structure in such markets and their impact on firm productivity:

- First, markets with strong network effects such as computer software may be inefficient because they show a tendency towards monopolization (Arthur, 1989; Koski and Kretschmer, 2004). Microsoft having achieved and maintained a strong monopoly position over several decades is just one example, but many ICT markets are highly concentrated despite the fact that classical entry barriers seem to be fairly low, especially for software markets where no physical infrastructure has to be built. However, unlike in conventional markets, the static inefficiency arising e.g. from monopoly prices has to be weighed up against the larger network effects that arise from having a single dominant network (Regibeau, 2004). Moreover, it is unclear whether dominant players in network industries charge actually do charge monopolistic prices.

- Second, for complex and complementary goods, market dominance may be translated to other product groups. For example, PC and server operating systems have been shown to be highly interdependent and that there is some evidence of market power translating from one to the other (Van Reenen, 2006; Genakos, Kühn and Van Reenen, 2008).

- Third, network effects may delay technological progress because a strong installed base may make it relatively more risky to adopt a new technology without a similarly-sized installed base. Such excess inertia (Farrell and Saloner, 1985; Kretschmer, 2008) may imply that new software technologies get adopted much later, or not at all, conferring even more market power to whoever sets the first standard.

The points outlined above indicate that the market structure of ICT markets may also have a tangible effect on the efficiency of ICT-using firms because they may either be forced to use software at higher than competitive prices (monopoly power), may be restricted in their choice of complementary products (translated market dominance), or continue using an outdated technology (excess inertia).

D. *Conclusions and Future Directions*

The literature on ICT adoption and diffusion is surprisingly underdeveloped. Arguably, this is probably because it is only since the mid-2000's that enough time and data has accumulated to allow the modelling of long-run diffusion patterns. Given what has been outlined above, a number of directions for future research are apparent:

- There needs to be a stronger link between the theory of technological diffusion and empirical research practice. Very few of the existing studies have a formal grounding in the type of framework outlined by Karshenas and Stoneman (1993).
- A wider range of ICT outcome variables is needed to capture different relationships. For example, internet technology adoption is the dominant focus of the US literature. It would be useful to lead the analysis of adoption with a general measure (for example, PC adoption as in Beaudry, Doms and Lewis (2006)) and then break down the components of ICT into individual components.
- Key candidates for these individual components of ICT include: total PC adoption, PC adoption by hardware vintage, inter-firm network infrastructure, within-firm network infrastructure and e-business technologies (ERP, DBMS and specialist OS).

- The management practices and organizational structure of firms needs to be included as a key determinant of adoption. In general, there also needs to be a consolidation of the industry-level variables used in these studies (e.g.: industry and region characteristics such as skills, wage, trade competition, regulation and local infrastructure).
- The next stage of research needs to consider factors that are exogenously influencing adoption rates. These exogenous factors can then be used as viable instrumental variables to determine the causal impact of ICT on firm outcomes.

I.4 ICT in the Public Sector

By definition, e-government is simply the use of information and communications technology, such as the Internet, to improve the processes of government. The general goals of e-Government are to make public services more efficient, responsive, transparent and diverse. These goals can be achieved in a number of ways.

- Firstly, E-Government **improves efficiency in mass processing tasks** and routinized public administration activities. Internet-based applications are a primary tool in this regard as they have the potential to generate savings on data collection and transmission, as well as the dissemination of information to the public.
- Secondly, there is scope for E-government to **improve the interaction of citizens with the government**. This potential relates mainly to access to information with the implication that this access may act as a check-an-balance against government corruption.
- Thirdly, the spread of e-government methods has the potential to improve the efficiency of **business-to-government interactions** and relations.
- Finally, the government's role as a **purchaser of private sector ICT** services and as a **provider of important infrastructure** means it has big impact on the structure of national ICT markets.

In some respects, the public sector shares the same challenges as the private sector when it comes to efficiently exploiting ICT. As discussed elsewhere in this review, a common challenge is   the need to combine the introduction of the new technologies with organizational change. This may represent a significant problem for public sector organizations, which are typically organized into bureaucracies that are not necessarily exposed to market-based incentives. Another factor that needs to be taken into consideration is the matching of services to user needs. The most prominent example of this is the need to recognise significant inequalities of ICT access when introducing web-based public services. In line with the focus on incentives within public sector agencies there must also be recognition of the incentives for consumers to respond to and take-up electronic public services.

Another empirical challenge is the problem of measuring output or productivity in the public sector. Although there have been improvements in recent years the absence of clearly defined outputs or market prices poses significant challenges. There are exceptions however. In healthcare (which has a large public sector component in most countries), indicators of performance include clinical outcomes and there are studies examining the take-up of ICT-related innovations (such as emergency ambulance calls in the US – see Athey and Stern, 2002, on "enhanced 911"). Like the private sector diffusion is slow and the impact

heterogeneous, although there appears to be significant health benefits. The recent study of Garicano and Heaton (2007) on policing in US cities finds that although ICT had little effect on crime average, when ICT was combined with an important organisational innovation (COMPSTAT) there were significant improvements in police productivity. There are also the mixed results from schools and ICT discussed earlier (Angrist and Lavy, 2002, Machin et al, 2006).

Most evidence of ICT take-up in the public sector comes primarily from ad-hoc and country specific surveys. Arguably, this approach has emerged by necessity as there are few consistent datasets on public sector ICT available across countries. With respect to country-specific resources the available data covers (OECD 2007a, 2007b):

- ICT expenditure and employment by government (Australia and Finland);

- Use of technology by government organisations (Canada, Finland and Japan);

- Provision of electronic services by government organisations (Denmark, Finland and Japan); and barriers to, and

- Impacts of, the digitisation of government (Denmark).

- The annual Cap Gemini survey of the availability of online public services in Europe. This survey measures a group 20 services across 27 EU countries as well as Iceland, Norway, Switzerland and Turkey.

While consistent, cross-country data is naturally preferred some of this within-country evidence is revealing in itself. For example, the annual survey of electronic commerce conducted by Statistics Canada shows that the internet and corporate websites are close to being universally adopted in the Canadian public sector with adoption rates rising from 88% in 2002 to 93% in 2003. Other Canadian data indicate that these rates of technology adoption in the public sector are similar to those in large private sector enterprises.

Detailed evidence on the impact of e-government initiatives for both consumers and citizens is still very thin. This is largely the result of data constraints and the difficulties in applying precise cost-benefit analysis (CBA) in this area. For example, the process of conducting a CBA is complicated by the complex changes that are often associated with the introduction of e-government. These include organisational re-structuring and major changes in IT systems which make it hard to separate direct and indirect costs or benefits. The OECD (2007b) identifies only two countries that have developed frameworks to evaluate multiple e-government initiatives. Australia and the United Kingdom have attempted to summarise the aggregate case for e-government projects by using their own internally consistent methodologies. These methodologies are applied across a group of large e-government projects.

- In Australia, the National Office for the Information Economy surveyed 38 e-government projects (NOIE, 2003). The user survey conducted as part of the evaluation estimated cost savings of AUD 14.62 per transaction compared to previously used channels. Amongst the private sector, businesses estimated savings of over AUD 25 per interaction. The NOIE (2003) analysis identified 24 projects that claimed either cost reductions or increased revenues. Against an estimated investment of AUD 108 million, the 24 projects considered were expected to achieve cost reductions of AUD 100 million. This represents a benefit/cost ratio of 92.6%.

- The UK government's study of 14 e-government projects found that all but one forecast positive returns. The payback periods for these projects ranged between four months and 11.5 years, with a mean of 4.8 years.

As far as the **role of e-government for businesses** is concerned, several areas have been identified (UNDP, 2007), especially for SMEs:

- First, as suggested above governments are important players in the e-commerce market. In cases where the government begins using e-procurement techniques to organise themselves there is a strong incentive for SMEs to take up e-commerce as well.

- Second, governments can use ICT to provide more efficient and transparent service for business. Examples of these include customs clearances, business licenses, regulatory requirements and dispute resolution mechanisms. The lack of transparency entailed in these processes can undermine the international competitiveness of SMEs.

- Thirdly, a role for e-government in improving transactions and general relations between firms and government services has been canvassed by Chevallerau (2005). These benefits include: the improved quality of government information available to businesses, the reduction of processing time, falls in the administrative burdens of regulation, lower processing fees (where applicable) and improved service levels.

- Fourthly, the idea that the implementation of new ICT investments could have a "demonstration effect" that encourages uptake in the private sector is also widely discussed. There does not yet seem to be solid empirical evidence for this hypothesis. In the next stage of this project it will be possible to test this hypothesis by comparing leads and lags in ICT uptake in different countries at the establishment level.

- Finally, governments control the legal, policy and regulatory frameworks that shape the uptake of e-commerce by SMEs. For example, a recent OECD paper (OECD, 2005) identifies a number of institutional barriers to e-commerce with a focus on payment, delivery and guarantee uncertainties over contracts. Wide variations in these barriers were observed across countries with payment uncertainties relatively important in Italy, Spain, Austria, the United Kingdom, and Portugal. Payment uncertainties appeared to affect smaller firms more in Spain, the United Kingdom and Finland. On similar lines, the Eurostat Community Survey on ICT usage by Enterprises reports that "Security problems concerning payments" and "Uncertainty concerning legal framework for Internet sales" as leading barriers to increased ICT usage.

I.5 How is the Internet Affecting Consumption Patterns?

A. Differences in ICT Consumption Across Countries

The extent to which ICTs are able to affect consumption patterns depends crucially on the adoption of key technologies such as PC's, Internet and broadband connections by households and individuals. Recent studies (OECD, 2008) suggest that the diffusion of these technologies has risen considerably over time. For example, total household expenditures on ICT have increased substantially since the 1990s, and more than any other consumption category (OECD, 2007). Looking more specifically at PCs, while in 1994 on average only 24% of households had access to a home computer across OECD countries; in 2006 the same statistic

rose to 69%. Since PCs and Internet may also be available outside the household, these figures are likely to underestimate actual usage rates[12].

Although ICTs have undoubtedly widened their diffusion among households, significant heterogeneity across countries persists. In 2006, the percentage of households with a PC across OECD members ranged between 50% in France to 80% in the Netherlands. Similar differences are found in the average percentage of households with a broadband connection during the period 2002-2007. This figure ranged between approximately 20% in Italy to almost 80% in the Netherlands.

The cross-country differences in ICT adoption by households can be explained by supply and demand factors. From the supply side, competition in the telecommunication sector is seen as a key driver of ICTs, leading to price declines in household Internet availability. Increases in the quality of goods (particularly in terms of computing power) also play an important role for ICT diffusion.

From the demand side, the OECD identifies three main determinants of ICT adoption by households: educational attainment, age and gender. The educational attainment of the head of household is highly correlated with PC uptake (OECD, 2004). Differential skills levels among adults may also have a magnifying effect on ICT adoption, since parents' education is associated with PC use by their children. Recent figures show that the gap in PC adoption by households with high and low levels of educational attainment is significant. For example, in Italy in 2007 70% of households with high educational attainment reported to have an Internet connection at home, while the percentage dropped to less than 20% for lower levels of education. It is worth noting, however, that this gap is considerable smaller in other OECD countries (such as Sweden, for example). Furthermore, as ICTs continue to diffuse, the role of skills in determining adoption is deemed to decline over time. For example, in Sweden the gap in the percentage of households with a PC between high and low educational attainments has declined from 30% in 1998 to less than 20% in 2005.

Age also appears to play a major role - with older age groups using ICTs less intensively and with slower internet connections - although generational differences are attenuated among individuals with higher educational attainments and age of retirement. As ICTs become ubiquitous among younger individuals, generational differences in ICT uptake are likely to decline, even if heterogeneity in the way technologies are effectively used may persist.

In terms of gender, males tend to use ICTs more intensively. These differences are particularly acute among older generations and with respect to newer technologies. However, microdata studies which analyse relative importance of gender once skills and age differences are taken into account (Frydel, 2006) tend to show only a marginal role for gender, while they confirm the prominent role of education and age (even controlling for household income) in explaining ICT adoption.

As PCs and Internet connections continue to diffuse across countries, differences in ICTs *access* are likely to decline over time. It has been noted, however, that heterogeneity in ICT *use*

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[12] In comparison with other technologies, however, the speed of diffusion of PCs is typically slower than, for example, mobile phones and TVs. This reflects the more demanding skill requirements associated with PC use. Broadband diffusion, facilitated by the pre-existing PC infrastructure, has instead been characterized by much faster adoption rates (OECD, 2008).

is likely to persist and, possibly, widen in the long run. For example, recent studies (Hargittai, 2002) emphasize the importance of socio-economic factors in explaining the number of different activities undertaken on the Internet, and the ability to efficiently retrieve information online. Similarly to ICT access, skills, age and gender appear to be significantly correlated with a higher number of activities undertaken on the Internet. For example, the gap in the use of Internet banking between high a d low skills individuals in Sweden appears to be have increased over time, while in Finland 40% of men between 15 and 29 years tend to use Internet for more than 12 different purposes, versus 10% of men between 50 and 74 years (Sirkiä et al, 2005). Similar findings are documented in Canada, the Netherlands and, to a lesser extent, France.

These differences are amplified by the availability of fast broadband connections, which have been shown to facilitate existing online activities, and to expand the number of Internet users. The effect of broadband seems particularly important for specific uses, such as Internet banking, downloading activities and online shopping.

To summarize, ICT access undoubtedly appears to have increase over time, although cross-country heterogeneity still persists. Major differences are however appearing in the way households and individuals effectively use ICT, both in terms of number of activities and their nature. Differences in both ICT access and use across individuals are correlated to supply and demand factor. Among demand factors, a prominent role is played by education, age and gender.

B. Effects of ICT on Prices and Industry Structure

Going beyond the topic of ICT diffusion across countries, a large number of studies have looked at the impact of the ICT and – more specifically – the Internet, on price levels and price dispersion.

Price dispersion is defined as the distribution of prices (such as range and standard deviation) for items with the same measured characteristics across sellers at a given point in time. Price dispersion is clearly important for consumers as it affects their search and purchase behaviour (Hopkins 2006). For sellers, it reflects the pricing strategy of competitors and their interactions. For the market, it is an important measure of information efficiency. Conversely, the minimum or average price are an indicator of how competitive the market is and, therefore, how close prices are to marginal cost.

The effect of ICT on prices and their dispersion is mostly analyzed in the context of search goods and their associated costs. More indirectly, ICT could also affect the production and especially distribution costs of goods, and although there are numerous examples of this (most notably Amazon.com) the economic analysis has not gone beyond postulating a general cost advantage of internet retailers over conventional ones with the corresponding advantages in pricing and competitiveness. Another channel through which ICT may affect prices and price dispersion is through menu costs. Online markets in principle should have low menu costs and allow continuous price revisions. The effect of a decrease in search costs on average prices and price dispersion has been analyzed in much more detail than a decrease in distribution costs and menu costs. Therefore, the following section will discuss the theoretical predictions and the subsequent empirical findings in this light.

It is useful to think of two market extremes as anchors: First, in a free-entry market without search costs and homogenous products will experience prices at the perfectly competitive level, that is, marginal cost. Raising prices is not profitable for any supplier as consumers would not

purchase the same good at higher prices. As all firms will charge the same (competitive) price, there is therefore no price dispersion. The other extreme introduces a (small amount of) search costs in an otherwise identical market (free entry, homogenous goods) and finds the so-called "Diamond paradox" (Diamond, 1971) which states that even a small amount of search costs will be sufficient to maintain an equilibrium in which all suppliers charge monopoly prices and consumers do not search because they expect prices to be identical across suppliers. Thus, prices are at the monopoly level and price dispersion again does not feature in equilibrium. From this background, a number of papers set out to establish the theoretical possibility of equilibrium price dispersion.

In an overview paper of the theoretical (and some empirical) literature on price dispersion, Hopkins (2006) finds that price dispersion is an empirical stylized fact, but theoretically hard to justify. Subsequent models (Salop and Stiglitz, 1977; Varian, 1980) achieve price dispersion by assuming two consumer groups, one "informed" (the mechanism of obtaining information is frequently modelled through a "clearing house" – a central organization that has information on all prices and dispenses this information to anyone who asks) and one "uninformed" (equivalent to consumers with infinite search costs). Firms will then weigh up the likelihood of making a sale to informed consumers (which they will only make if they charge the lowest price and consequently a low margin) with the potential (higher) margins from selling to uninformed consumers. In this context, price dispersion is a possibility as some firms charge lower prices to sell to informed consumers, but suppliers may want to increase prices if the profitability of charging low prices with many competitors is low. It is commonly assumed that search costs decrease with the introduction of ICT and especially the increased penetration of the internet. First, the internet makes it easier to search for prices from different suppliers, leading to a direct decrease in search costs, and second, specialized price comparison sites (shopbots) can take on the role of a clearing house informing consumers. In both cases, it is plausible to assume that the number of "informed" consumers increases, which has two related effects: First, charging lower prices becomes more attractive because there are (relatively) more consumers who compare prices and base their decisions on the cheapest price, which leads to overall price decreases. Second, the fact that deviating from this strategy is less attractive because the likelihood of selling to an uninformed consumer has decreased – there are simply less of them. Consequently, price dispersion is also likely to decrease with increased internet use and the proliferation of shopbots.

Interestingly, recent empirical research has not found results consistent with the above predictions. Prices have not decreased to a level even approaching the competitive level, and price dispersion remains a long way from the predicted convergence towards zero in the absence of search costs. Given the literature on prices and price dispersion in internet markets is vast and growing; we first review the results on price levels and then the results on price dispersion. Pan et al. (2003) give a review of the earlier empirical work, while Hopkins (2006) lists a few empirical papers relevant to an explicit testing of theoretical models of equilibrium price dispersion.

Price Levels

- Bailey (1998) studies CD and book prices and finds that prices of these products on the Internet were higher than those in the conventional channel, a result which is confirmed by Lee and Gosain (2002), who compared prices of music CDs between internet retailers and notable "brick and mortar" retailers in 1999 and 2000, and find that prices were comparable (and not lower, as theory would predict) for current hit albums.

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However, Lee and Gosain (2002) also find that prices are lower on the internet for other products.

- With the emergence of shopbots, a number of studies focus on the specific effects of their use and find results that are more in line with the expectations from theory. For example, Tang et al. (2007) find that an increase in shopbot use in the early (1999-2001) internet book market by 1% is associated with a price decrease of .41%. Along the same lines, Brynjolfsson et al. (2008) find that price elasticities in a shopbot-enabled market are fairly high (-7 to -10), which suggests that consumers switch easily to cheaper suppliers. However, even this "nearly perfect" market still displays significant search costs, and consumers could still achieve significant savings from searching for lower prices.

- The general consensus in the literature is that especially in more mature internet markets, shopbots have the expected effect of lowering average prices. Although the effect is stronger now than in the early phases of the internet, price levels have not reached (and show no signs of reaching) the competitive level, suggesting that although consumers are increasingly sophisticated and therefore face lower search costs than in early internet markets, these costs are still significant in the minds of consumers.

Price Dispersion

- Price dispersion again has not disappeared with the emergence of the internet. All studies focusing on pricing behaviour in internet markets find some price dispersion remaining. More interesting therefore than the documentation that such dispersion still exists (e.g. Clemons et al., 2002; Bakos and Brynjolffson 2000) is the comparison of pre- and post-internet markets or even internet markets over time. An exception is the study by Clay and Tay (2001), who study price dispersion within Amazon across countries and find significant dispersion even there.

- As an example of the "dynamic" view on price dispersion, Scholten and Smith (2002) compared price dispersion levels in traditional retail markets of 1976 with those in Internet retail markets of 2000 and find that dispersion has remained virtually constant. It has, however, been suggested that this may be an artefact of the relatively nascent state of internet markets and that price dispersion does decrease over time. Brown and Goolsbee (2002) investigated the impact of Internet comparison shopping on life insurance market during 1992-1997 and found that price dispersion initially increased with the introduction of Internet search sites, but then decreased as Internet usage spread. Brynjolfsson and Smith (2000), who looked at book and CDs sold through 41 online and offline retail outlets from February 1998 to May 1999, found that price dispersion was smaller online than it was offline, which confirms the theoretical predictions.

- In an overview article, Baye et al. (2006) find that price dispersion persists even in internet markets and that the key factor in determining price dispersion is the number of firms selling a particular good. As the emergence of the internet coincides with a general shakeout of the number of internet retailers, the two effects may often be conflated.

Branding and Reputation on the Internet

One of the most plausible explanations for the often perplexing results on the persistent ability of firms to charge different prices and to sustain price above marginal cost is the emergence of firm reputation and branding as an important factor in the purchasing decision. This is especially salient in internet markets where payment has to be made in advance and/or the quality of a product cannot be observed prior to purchase. Although Baylis and Perloff (2002) find that even "bad" firms can maintain high prices, the consensus is that a reputation for timely delivery, reliable product quality and unfussy exchange policies will enable a firm to consistently charge higher prices for the same products. Since reputation takes time and effort to build, dispersion among firms with different reputations can be expected. Focusing on eBay sellers, Cabral and Hortacsu (2008) find that the evaluation mechanism provided by eBay works in the expected way as higher seller reputation increases the likelihood of making a sale and the average prices achieved. In a similar vein, Baye et al (2006) show that branding does not eliminate price dispersion, but enables firms to trade on their reputation rather than offering the cheapest price. Thus, while the literature now accepts that price dispersion exists even in markets with low or even zero search costs, the mechanism(s) by which prices are kept high and dispersion is maintained has not yet been established completely. Reputation and branding appear to be two of the frontrunners, however.

In summary, prices and price dispersion have not gone the way empirically initially predicted by theorists who focused on search costs of key drivers for high prices and persistent price dispersion. Instead, prices remained above marginal costs (even if slightly lower, across a number of studies, than in conventional markets) and price dispersion continued to exist (even if there appears to be a downward trend with increasing maturity of internet markets). Researchers have therefore started looking for alternative explanations for this limited effect of the internet on prices and price dispersion and placed particular emphasis on the role of reputation and branding in stabilizing prices and price dispersion. It certainly appears, however, that the empirical literature is leading the way in finding unexpected (or unexpectedly stable) patterns that pose a challenge for theorists and theory-driven empiricists.

II. ROLE OF ICT IN DRIVING THE KNOWLEDGE ECONOMY

II.1 Role of ICT in Knowledge Intensive Activities

The idea of a "knowledge economy" has been popular since the mid-1990s. Smith (2000) identifies four key themes of the knowledge economy literature. These are:

- The argument that knowledge has become more qualitatively and quantitatively important to economic activity.

- A perception that knowledge-based products have become more important, both as final-demand products and intermediate goods.

- A view that economic activity has become more dependent on codified knowledge (that is, formally defined scientific information).

- Finally, there is a widespread consensus that ICT is a major catalyst for the knowledge economy. That is, ICT has reduced the costs and physical constraints of collecting and disseminating information. Furthermore, through its communication function ICT has

facilitated the creation of new knowledge through more efficient processes of collaboration.

In turn, the literature has defined a sub-sector of knowledge intensive industries (mostly services) that play a central role in the knowledge economy. These industries are important firstly because they are the industries that are advanced users of knowledge and secondly because they also provide important service inputs into other industries. An example of a classification of knowledge intensive services (KIS) is given in Table 6. These industries are mainly professional service industries such as finance, legal services, recruitment, management consulting, marketing, design, and R&D (Broersma and van Ark (2007); Windrum and Tomlinson 1999).

In empirical terms the measurement of KIS industries has been conducted in two ways.

- Firstly, there was an early OECD classification dating from the 1980s. This classified industries according to their R&D activity. Specifically, this approach defined thresholds for technological intensity based on R&D expenditure. For example, industries which spent more than 4% of turnover on R&D were classified as "high tech" and so on. Clearly, the problem with this definition is that it rests on a single indicator. As a result it ignores knowledge related activity that is not measured by formal R&D (for example, service related product innovations and skill-intensive services in general) (Smith 2000).

- Secondly, industry-code groupings have become more common. These are based on quasi-subjective selections of service industries with one example given in Table 6. These basic classifications encompass most areas of business, legal and design/R&D services. However, this part of the literature does not tend to formally define the choice of industries in terms of characteristics R&D or skill intensity.

The other empirical issue relating to KIS industries is evaluating their contribution to economic activity in other sectors. The services produced by these industries are frequently cited as intermediate inputs into other industries. The main approach to measuring this contribution is therefore based on input-output (IO) tables that measure the inter-industry flow of goods and services inputs. A key study that follows this approach is Broersma and van Ark (2007). Analysing data for the Netherlands they use IO tables to nest the contribution of KIS intermediate inputs into a production function framework. The "diffusion" of KIS inputs throughout the economy is therefore quantified with reference to inter-industry flows. Their study finds that KIS inputs have a significant positive relationship with labour productivity both on their own and also through an interaction with ICT inputs.

However, it must be noted that there are still significant gaps in the literature on KIS industries. In particular the two main gaps are:

- The elaboration of a clear classification system for KIS industries. For example, it would be useful to characterise the KIS industries in terms of R&D intensity, levels of human capital, innovation outputs (e.g.: patents, trademarks), productivity, and types of output. Developing these characterisations would allow researchers to then differentiate between the KIS industries (e.g.: high formal R&D industries versus low R&D industries).

- The literature still lacks a comprehensive study of KIS industries that uses internationally comparable microdata. This is necessary for making comparisons of

performance across different economies, and more generally for estimating firm level production functions.

II.2 ICT Uptake, Innovation and R&D Investments and Returns

A. Knowledge Capital – The Roles of R&D and ICT

At the most basic level, R&D and ICT share similarities in the sense that they are examples of technological or "knowledge" capital. However, R&D is distinguished by the fact that it is a type of technological capital that is specifically intended to produce new innovations. A detailed literature has shown that there are quantitatively significant benefits from R&D at the firm level with output elasticities ranging from 5-30% and rates of returns between 10-80%.

In contrast, ICT is a more general input and while it can be used to foster a firm's innovative efforts (particularly when considering the possible interactions with organizational structure and management practices) it can also be deployed for short-run use in production. In this context, ICT is another capital input in the production without any necessary link to innovation. Our discussion of ICT and R&D below therefore focuses on two issues: the issue of spillovers from technological capital and the potential complementarity of ICT and R&D in the production function.

Practically, the key difference between ICT and R&D is that R&D has a recognized capacity to generate spillovers and social returns as groups outside the originating firms benefit from knowledge generated by particular innovations (Griliches 1991). The evidence so far (summarized in Cheryan et al 2006) suggests that there is limited scope for such spillovers when it comes to ICT. It seems that ICT is more similar to physical capital than R&D with little indication that the intense use of ICT generates spillovers in adjacent industries or regions.

However, it is still possible to envisage a role for ICT in fostering innovation by supporting the effectiveness of R&D expenditure. This could be seen most simply by estimating an interaction term in the production function. Such an interaction could be interpreted as an indicator that firms that ICT-intensive firms benefit both directly from the ICT investments as well as indirectly thorough the effect that ICT has on the productivity of R&D. While appealing, this type of conclusion must be treated with caution. An observed interaction between ICT and R&D could simply be an indication of the general unobserved productivity characteristics of a firm, that is, a flag for high-tech, high-productivity firms. A rigorous assessment of the interaction of the ICT and R&D in the firm production function would therefore require some exogenous variation in one of the components. This variation (say, a change in government R&D subsidies) could then be interacted with a firm's baseline ICT intensity to estimate the magnitude and significance of the proposed interaction. So far neither of the literatures on ICT and R&D has comprehensively implemented this type of research strategy.

B. R&D Collaboration and the Role of ICT

Basic economic theory suggests that firms will participate in collaborative research activity only in situations when the expected benefit of doing so is positive. For example, firms may want to share costs or skills in developing an innovation. The role of ICT in this context lies in its scope to lower the costs of communication and therefore increase the probability that a co-operative relationship will emerge. However, the major factor driving research collaboration is the extent to which innovations are appropriable. That is, collaborations are determined by the degree to

which a firm can capture the benefits flowing from an innovation. It is these two factors – appropriability and communication costs that underpin the decision to collaborate.

The literature on R&D co-operation is mainly based on the Community Innovation Survey (CIS), a European survey of firm-level innovation activities. The CIS is unique insofar that it has pan-European information on both innovation and respondent's views of where the (multiple) sources of their innovation activity came from. Key contribution include Abramovsky et al (2005) and Cassiman and Veuglers (2002). We concentrate here on Abramovsky et al (2005) which reports on collaborative research patterns in France, Germany, Spain and the UK:

- Research collaboration is broadly defined as encompassing: co-operation with customers and suppliers (vertical co-operation); co-operation with competitors (horizontal co-operation); and co-operation with universities or research labs.

- The highest incidence of co-operative activity is found in France and the UK, with Germany and Spain following behind. The French and UK strengths in collaboration are based on the manufacturing sector while the incidence of activity in Germany and Spain is evenly split between manufacturing and services.

- Vertical co-operation plays the largest role in France and the UK with 14% and 20% of all innovative firms engaged in this type of co-operation respectively. There is very limited horizontal co-operation with competitors (approximately 6% on average across all of the countries studied). Co-operation with universities and research labs is evenly spread across the countries, with an average rate of 14% across all innovating firms.

- Firms using strategic methods (e.g.: secrecy or complexity in designs, forward planning) were found to be the most likely to participate in co-operative agreements. This is understandable to the extent that it is an indicator of those firms that are best able to appropriate rents from their innovations. A distinctive result emerged for Spain in relation to financial constraints – firms seemed to be undertaking collaborative research there in order to overcome financial constraints and ameliorate perceived economic risks.

There are few explicit tests of role in this literature so far. One exception is the study by Agrawal and Goldfarb (2008) which examines the impact of early internet technology ("bitnet" connections) on research collaboration between university engineering departments in the 1980s and 1990s. They consider a sample of 270 universities and measure output via a count of publications in top scientific journals. They find that bitnet connections increased the probability of collaboration by approximately 40%. Furthermore, the effect was strongest for co-located universities that were of different levels of quality. For example, they found that bitnet connections were associated with collaborations between "top tier" and "second tier" universities located in the same region. One interpretation given here is that the fall in communication costs induced by bitnet connections facilitated the division of labour in research collaboration. That is, lower cost research tasks could be undertaken at the second tier sites while higher cost tasks (often requiring more advanced laboratory equipment) could be conducted at the first tier site. Interestingly, this finding is consistent with hypotheses and evidence being advanced in the recent literature on outsourcing and offshoring discussed in section III.C.

However, its empirical implications can still be drawn out. In this context ICT investments are likely to be an indicator of general unobservable characteristics of firms, particularly their innovative capabilities. Any estimate of an ICT variable in an equation explaining co-operative

behaviour is therefore likely to be picking up this unobserved feature rather than the effect of ICT per se.

Another way to consider this question is to nest it within the overall issue of falling travel and communication costs. Griffith, Lee and Van Reenen (2007) consider the pattern of international knowledge spillovers using patent citations. They find that the extent of "home bias" (or propensity to cite inventions that are generated with local national borders) has fallen sharply over time with very little home bias remaining in leading research sectors such as ICT and pharmaceuticals. Other studies have also found some reduction in the importance of geographical distance[13]. Although this is consistent with the hypothesis that ICT has lowered the costs of knowledge diffusion, it is rather indirect evidence.

C. *Using Software Adoption to Identify Product and Process Innovations*

When discussing the impact of information and communication technologies on innovation, we need to distinguish between the development and the adoption of innovation. Specifically, it is important to consider if ICTs facilitate the generation of innovation, for example by reducing the cost of storing information that is used in the R&D process or by developing simulation tools that make it easier to assess changes in product design. This impact of ICT is likely to be particularly relevant in research-intensive industries such as aircraft engineering, biotechnology, or the pharmaceutical industry. On the other hand, for a large number of other industries it is more important to consider the adoption of innovations generated elsewhere, i.e. in other industries. That is, we need to distinguish between innovation *generators* and innovation *users*.

While most research focuses on innovation generation, Kretschmer, Miravete and Pernias (2008) focus on innovation adoption by using specific software as proxy for product and process innovation, respectively. This approach is useful for identifying the impact of a change in competitive conditions on firm incentives to adopt these different types of innovation. As an example, Kretschmer et al. (2008) study the adoption of two software packages, specifically human resource management software (HR), and applications development software (APPS), respectively. Furthermore, this study uses the AMATECH data which will be used as a major input into the final report and therefore provides a good example of the flexibility of this data and the applications that will be developed in the second interim report.

HR management software refers to the range of software applications that regulate all the personnel related data flow, such as tracking employees' participation in benefits programs, administering the recruiting process, and implementing human resource practices more efficiently. In essence, HR software is used to support human resource processes that were previously administered manually facilitating savings on administrative expenses, especially personnel. Operating costs of HR management software adopters are, ceteris paribus, likely to be lower than those of non-adopters – and it seems reasonable to assume that the cost reduction is proportional to the number of employees in the firm, given many HR processes take place per employee. Therefore, HR or similar types of software can be used to proxy for process innovation.

APPS development software grew out of programming languages such as C++, Basic, or Fortran and contains added functionality like debugging or requirements testing to facilitate the development of own, customized software applications. Thus, APPS effectively provides a user

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[13] Kim et al (2006) examine economic and finance departments in universities and find that the advantage of location has diminished over time.

interface and toolbox for programmers. The most prominent examples of application development software are Microsoft's Visual Basic at the low end and Borland's Delphi at the high end. Applications are highly industry-specific, highly specialized, and often support mass customization like "car configurators" (web based software where potential buyers can customize their desired automobile) or specialized software components that enter the end product. Typically, APPS facilitates applications development where no ready-made applications exist or where its customization would be too expensive. Since ready-made applications dominate the market for improving the efficiency of standard business processes (like HR management), and customizable products like SAP ERP (an enterprise resource planning system that supports typical functions in an organization such as finance, controlling, materials, and sales), regulates industry-specific material and information flows across different processes within the firm, it seems plausible that APPS software will most commonly be used to develop fully customized applications for tasks that add value to the product or service sold. These are sources of differentiation among firms and are therefore both (i) firm-specific and (ii) unlikely to be outsourced to third parties. We thus believe that firms adopt application development software for revenue-enhancing reasons, i.e. can proxy for a product innovation.

II.3 ICT and Management/Organization

A substantial case and interview-study based literature[14] and econometric work has examined the causes of variance across firms in the pace and success of ICT adoption. There is growing evidence that the returns to ICT are linked to the internal organization of firms, and to the type of management practices they adopt.

From a theoretical perspective, the complementarity between ICT and organization arises from the fact that these technologies change the information available within the firm. This, in turn, shapes the internal organization of the firm (e.g. Milgrom and Roberts, (1990); Brynjolfsson and Mendelson, (1993); Radner, (1993)). At the same time, a combination of organizational and technological innovation is required to deliver consistently high levels of customer service and reduce costs (Davenport, 1994).

Empirical papers fall into two main categories: The **adoption approach** postulates that firms behave in a profit-maximizing manner and would therefore only combine organizational characteristics (such as management, organizational structure and ICT) if they are complementary. Observing two of these simultaneously is taken as evidence of complementarities. The advantage of this approach is that researchers do not need reliable data on the profitability of the firm, which is often hard to come by. Conversely, the **productivity approach** observes profit levels and assumes that firms only maximize profits with an error. This approach identifies complementarities by looking at profits of firms that happen to use firm activities simultaneously vis-à-vis others that do not. If the former experience higher profits than the latter, two activities are said to be complementary. Both approaches face some problems, most notably the existence of unobserved heterogeneity that may be driving the joint use of practices (in the adoption approach) or profits (in the productivity approach). This makes quantifying the precise effect of complementary practices on profits difficult.

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[14] Blanchard (2004) discusses a number of industry-specific examples. Baker and Hubbard (1999) is an excellent example of applying econometric techniques to a case study of on-board computers in the US trucking industry. He finds that on-board computers had a major effect on the organizational structure of the US trucking industry because it became easier to measure output in a transparent way.

Another general issue relates to distinguishing organizational structure from management practices since both can be considered as unobservable "intangible assets". The approach taken in Bloom and Van Reenen (2007) is to explicitly define management practices as activities that direct and organise the regular or "day-to-day" production processes of a firm. Most simply, these can be grouped into labour force or "people management" practices and production or "operations management" practices. In contrast, organizational structures represent the fixed or slowly-changing features of a firm's intangible assets or structure. The most prominent example of organizational structure in the literature is the degree of centralization in decision-making. To be clear, management practices are deployed *around* a given centralised or decentralised organizational structure making it possible to measure the two concepts (management and organization) separately.

On the empirical side, several case studies have documented how ICT deployment affects authority relationships and decentralization of decision authority (Bresnahan, Brynjolfsson and Hitt, 2002). Various empirical papers have also attempted to estimate the complementarity between ICT and organizational structure using large samples of firm level data. A range of these studies include:

- Bresnahan, Brynjolfsson and Hitt (2002) combine data on organizational structure, using a cross-section survey of managers in 1995, with ICT data on 300 large US firms observed between 1987-94. Organizational structure is measured using questions on team working, and the extent to which workers have authority over their pace and methods of work. They find statistically significant and positive productivity effects from the *interaction* between organizational structure and ICT.

- Caroli and Van Reenen (2001) use French firm data covering 1992 and 1996 with indicators for the use of new work organisation and use of new technology. They find that changes in organizational structure are statistically associated with productivity growth, particularly when interacted with skills, although, the interaction is not significant when interacted with ICT.

- Using UK plant level data, Bloom et al. (2007) construct a panel of data on output and inputs, including ICT and non-ICT capital. They interact ICT capital with an indicator for whether the firm is part of a US multinational. They find that the US*ICT interaction is positive across several specifications and significantly higher than a similar interaction for non-US multinationals. They interpret the higher IT productivity of US multinationals as consistent with the idea that US companies have specific organizational structures which are complementary with ICT. They find additional evidence supporting this hypothesis using firm level data on organizational structure for a large cross-section of US and non US multinationals operating in Europe. Their results show a positive and significant interaction between ICT and a survey measure of organizational flexibility ("people management"). Furthermore, once the organizational structure-ICT interaction fully "accounts" for the higher output elasticity of ICT assets found for US multinationals.

- Again, the magnitude of the Bloom et al (2007) result is of interest. In their most stringent specification, a 10% increase in ICT capital is associated with a 1.4% increase in productivity when interacted with a score measuring a firms' "people management" practices and an additional 0.5% when interacted with a variable measuring "target management".

- Black and Lynch (2004) use two establishment surveys on organizational structure for 1993 and 1996 (e.g. use of high performance work systems) combined with data on ICT (in particular, the use of computers by non-managers use computers). They combine

with US Census data on the plants (the LRD). Estimating both cross sections and panel data they find that high performance workplace practices are associated with higher productivity, and in particular that the share of non-managers using computers is positively correlated with productivity.

- In terms of the actual measures of organizational structure used in these studies, they fall into two categories. The first category is typified by the Bresnahan et al (2002) study and revolves around measures of how actual production processes. Specifically, they relate to issues such as team work systems and the degree of autonomy in the completion of tasks. The second set of measures is typified by the Bloom et al (2007) study. The measures here focus on the quality of a codified set of management practices rather than specific ways of organizing production. At this stage of the literature it is not clear which aspect of these measures (i.e.: organizational structure versus management practices) generates a larger effect when combined with ICT.

It should be noted that the interaction between ICT and organizational structure might be more complex than expected. In a recent study, Bloom, Garicano, Sadun and Van Reenen (2008) combine a rich data set providing information on both hardware and software assets with a novel survey that provides measures of organizational decentralization. Their study shows that knowledge-enhancing technologies (such as ERPs and CADCAM) are associated with higher levels of decentralization, while communication technologies (which enable faster communication from top to middle managers) are significantly associated with more centralization. Similarly, Mahr and Kretschmer (2009) explore the connection between organizational structure, ICT use, and product market strategy. They find that both centralization and decentralization can be complementary to ICT use depending on firms' strategies. Specifically, firms focusing on exploiting existing markets and capabilities benefit from centralization supported by ICT, while firms exploring new geographical and product markets benefit from an ICT-supported, centralized structure.

Empirical work on this topic is made even more difficult because there is no commonly accepted definition of what constitutes the organizational structure of a firm. The literature agrees that the degree of centralization is an important element of a firm's structure, but other elements such as organizational culture, the interaction of formal and informal rules and the span of control as well as the steepness of a firm's hierarchy are also important elements that may be correlated with, but not identical to the level of centralization of decision-making. Mahr and Kretschmer (2009) run an exploratory survey on these aspects of organizations and find that a measure combining both formal and informal elements of organization generates comparable, although somewhat noisier results on the complementarities between organization, management and ICT. Nevertheless, measuring organizational characteristics is still underdeveloped compared to other dimensions.

II.4 ICT and Satisfaction of Employees

The relationship between ICT and employee well-being has been analyzed from different perspectives, such as labour economics, human resource management and information systems management. Here, we focus on three specific components of employee well-being:

1. **Job satisfaction,** i.e. the (psychological) well-being directly derived from the work domain;

2. **Work-life-balance**, i.e. the (psychological) well-being from properly balancing work and personal/family life;

3. **Job stress** which resorts to the more psychosomatic effects of work life.[15]

Several studies focus on the ***process of implementing ICT*** and its impact on job satisfaction and job stress. A classic differentiation of ICT implementation styles is the technology-vs.-end-user continuum, where a technology style focuses on technological considerations without taking into account psycho-social effects whereas an end-user style explicitly considers end-user experiences (Blacker and Brown, 1986; Salanova et al., 2004). The overall finding in this field is that employees which are given the chance to participate in the process of ICT implementation tend to have a higher job satisfaction and less job strain (e.g., Barker and Frolick, 2003; Korunka, 1993a; 1993b; Korunka et al., 1995; Korunka and Vitouch, 1999).[16] Giving employees proper ICT training and advice (Chang and Cheung, 2001; Korunka and Vitouch, 1999; Sandblad et al., 2003), as well as enough time to become familiar with the new technology, (Griffith and Northcraft, 1996) also increases job satisfaction.

In contrast with the early literature, Salanova et al. (2004) find that a "first time implementation style" (high pace of implementation with the goal of productivity improvement and only mediocre flexibility of the planned implementation process) is correlated to higher job satisfaction than a "continuous implementation style" (slower pace of implementation with the goal of higher product quality and very high flexibility related to the planned implementation process).

There are opposing views and findings whether ***ICT use*** is positively or negatively related to job satisfaction and stress. Hackman and Oldham's (1980) model of five core job characteristics (skill variety, task identity, task significance, autonomy, feedback) which positively influence job satisfaction is a tool for explaining this relationship (e.g., Grant and Uruthirapathy, 2003). In general, ICT increases the information endowment of individual employees, enabling them to improve the quality and quantity of their work. Additionally, the information exchange between employees is facilitated, enabling them to better coordinate their (team) work (Garicano, 2000; Dewett and Jones, 2001).

Among the studies which look at the direct impact of ICT use on employee well-being, ICT is generally considered to have two main effects. On the one hand, it can support and make an employee's job easier, which increases job satisfaction (Wastell and Newmann, 1996). On the other hand, ICT can also lead to information overload, a higher workload and an accelerated pace of work as well as to a feeling of inflexibility and dependence on ICT. This may result in reduced job satisfaction and increased job stress (Bradley, 2000; Edmunds and Morris, 2000; Sparks et al., 2001; Wastell and Newmann, 1996; Wastell et al., 1994) and more specific outcomes like burnout (Salanova and Schaufeli 2000; Salanova et al., 2000; Salanova et al., 2002). Intuitive examples for both effects are the use of the Internet or electronic mails (Adams, 1993; Bradley, 2000; Edmunds and Morris, 2000; Kraut and Attewell, 1997; Markus, 1994; Sproull and Kiesler, 1986; Straub and Karahanna, 1998; Teo et al., 1999; Whittaker and Sidner, 1997).

Most empirical studies on ICT's direct impact on well-being analyze particular types of ICT, finding evidence for both its positive and negative effects. Of great interest in the earlier literature was the use of video display terminals (VDTs) (Lindstrom, 1991; Smith et al., 1981;

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[15] We do not consider ergonomics, i.e. ICT's impact on employees' physical well-being.
[16] Of course, it is questionable if this finding is specific to the IT implementation process or if it is general to implementing technological or organizational innovations in a firm.

Steffy and Jones, 1989; Stellman et al., 1987; Smith, 1987). Ongoing interest is devoted to the impact of telecommuting on different aspects of well-being with a special focus on the social isolation from co-workers (Bailyn, 1989; Belanger, 1999, Cooper and Kurland, 2002; Crossan and Burton, 1993; DuBrin, 1991; Duxbury et al., 1998; Norman et al., 1995; Valcour and Hunter, 2005; Henry and Stone, 1995; Hill et al., 2003; Salomon and Salomon, 1984; Standen et al., 1999; Tomaskovic-Devey and Risman, 1993; Wiesenfeld et al., 2001).

Among further studies on particular ICT types are Kahn and Cooper (1991) who find no negative impact of the ICT used by dealers in London (traders in currency, wasp, bonds, etc.) on job stress, Grant und Uruthirapathy (2003) as well as Barker and Frolick (2003) who find enterprise resource planning (ERP) systems having positive impacts on many job characteristics of Hackman and Oldham's (1980) model (see above), as well as studies on groupware like video conferencing (Agius and Angelides, 1997; Kydd and Ferry, 1994) and Lotus Notes (Schultze and Vandenbosch, 1998). In a recent large-sample study on the working conditions of 2,500 French individuals, Martin et al. (2008) find two types of ICT (computer, internet) positively related to several aspects of job satisfaction and cell phones having ambivalent effects, increasing some measures of job satisfaction (promotion opportunities, enriching job) and decreasing others (more need to rush, more deadline-quality conflict, more need to handle incidents alone).

However, many empirical studies on ICT and work organization underline that ICT induces firms to provide their lower-level employees with greater autonomy and install a set of complementary high involvement work practices[17] like screening, training, performance reviews, teambuilding, self-managed teams, and broader jobs (e.g., Brynjolfsson and Hitt, 2000; Bresnahan et al., 2002). These high involvement work practices have in turn been found to positively influence job satisfaction in a number of studies (e.g., Bailey et al., 2001; Bauer 2004; Freeman and Kleiner, 2000; Freeman et al., 2000). Also, Autor et al. (2003) and Spitz-Oener (2006) find a complementary relationship between ICT and non-routine analytical and interactive activities, which might increase job satisfaction (Hackman and Oldham, 1980). The large effect of ICT was to replace routine tasks whether they are low skill (e.g. production work on an assembly line) or higher skill (e.g. bank clerks)[18]. Godard (2001) finds only a moderate use of high performance work practices having a positive effect on employee well-being. However, increasing levels of these practices weaken the relationship, which is even negative for some indicators of well-being. For example, in a study of working conditions in France in the 1990's, Caroli et al. (2002) find that two high performance work practices (quality norms, job rotation) are related to harder working conditions (higher risk of work injuries, more mental strain). Other studies assume that ICT leads to more codified and standardized working conditions (e.g., Autor, Levy, and Murnane, 2003; Spitz-Oener, 2006) and deskilling (e.g., Askenazy and Caroli, 2002), which might decrease job satisfaction (Hackman and Oldham, 1980).

Only a few studies have looked directly at the effects of ICT use on work-life-balance. The main question in this field is if ICT's tendency to blur boundaries between the work life domain and the family life domain allows employees to be more flexible in both domains or if negative spillovers from the work to the family dominate. Hill et al. (1998; 2003) find that IBM

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[17] The literature also calls these High Performance Workplace Practices or High Commitment Workplace Practices. All these terms describe a set of practices designed to elicit discretionary effort by employees by setting (pecuniary and non-pecuniary) incentives for high performance and creating an environment that facilitates the (both horizontal and vertical) exchange of information (Bryson et al., 2007).

[18] Interestingly this means that non-routine low wage jobs like cleaners have not seen their demand fall as a result of ICT. The Autor et al (2003) argument is that this is why there is a growing polarization in the labour force (especially in the 1990s) with groups of workers in the middle of the wage/skill distribution being worse affected by the rapid falls in quality adjusted IT prices.

telecommuters have indeed more flexibility than traditional office workers to meet both work and family needs. Nevertheless, they find that this is positive for work life mainly and somewhat negative for aspects of personal/family life. In interviews, handheld users valued the chance to reach colleagues and being reached more often, but also indicated greater challenges to protect personal life (Schlosser, 2002). Chesley (2005) finds cell phone use (but not computer use) to be associated with negative spillovers from work to family life over time, leading to increased stress and lower family satisfaction. Roswell and Olson-Buchanan (2007) survey 360 non-academic university staff members on their use of communication technologies (CT) (cell phones, e-mail, voice mail, PDAs, pagers) to perform their job during non-work hours. They find CT use positively related to work-life-conflict as reported by the respondents as well as significant others to the respondents (e.g. spouse, adult child, romantic partner). They find no gender differences for this relationship, but a stronger relationship for managers. Also, the use of CT in non-work hours is found to have a stronger effect on work-life-balance than "offline" work in non-work hours.[19]

II.5 ICT and the Market for Intangibles

Intangible assets such as patents, trademarks and firm-specific skills and capital have long been thought to have a significant impact on firm performance. This impact has been heightened by the emergence of ICT-related technologies. In the sections below we discuss two dimensions of this issue. First we provide an overview of ICT patenting. Patenting is the main measurable intangible asset produced by firms and ICT patenting is an important factor determining the productivity of the ICT-producing industries. Secondly we discuss the role of knowledge management applications in the workplace. These technologies (most often represented in practice by e-mail, groupware and database applications) are a major driver of the productivity effects of ICT that are familiar to casual observers. We discuss some key high quality studies and also discuss the recent rise of related knowledge intensive services.

A. Trends in ICT Patents

Patents are the primary policy tool used by governments to foster innovation. Simply defined, patents are property rights that allow the inventor to exclude others from making, using, or selling the invention for a limited period of time in exchange for obligations related to publicly disclosure and licensing. To be approved, inventions submitted for patenting must be judged to be "new, useful and non obvious". Patented inventions can have major impacts on the economy by introducing new products and processes that enhance productivity or even lead to the development of new areas of economic activity. This is the case of ICT patents[20] which have helped to create a variety of new industries and products such as personal computers, mobile phones, numerically controlled machine tools, and more recently wireless devices. In the following we briefly review the available evidence on ICT patenting trends, particularly in terms of cross-country trends.

Some recent studies (OECD, 2005, NSF, 2008) have documented the major trends in ICT patenting. Overall, the numbers of ICT patents granted by the US Patent Office (USPTO) and

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[19] There is no work to date on possible interactions between ICT use, certain managerial or organizational practices and worker well-being. For example, communication technologies may affect worker wellbeing indirectly by facilitating practices like teleworking or flexitime. Uncovering the precise effects and channels of ICT's effect on worker well-being would be a fruitful and important area of research, however, if the right data is available.

[20] The definition of an ICT patent is not straightforward (OECD, Science and technology Scoreboard). In what follows we use the definition of ICT patents developed by the OECD, which in based on the International Patent Classification System (IPC) and includes technologies in "Telecommunication", "Consumer Electronics", "Computers and Office Machinery" and "Other ICT".

the European Patent Office (EPO) have increased rapidly over the past 15 years. However, the data reveals some interesting differences between Europe, the US and Asia. US patenting intensity in ICT is not necessarily higher than its patenting intensity in other technological fields. In contrast, Asia has patented more intensively in ICT compared with other technology areas although this effect has been dissipating. The EU has a lower presence in ICT patents compared with the United States and Asia. However, five EU countries do patent more intensively in ICT compared with the rest of the EU. Finland and Ireland patent more in ICT compared with other technology areas while the UK patents at about the same level of intensity in ICT as for other technological specialisations. In the case of Sweden and the Netherlands they patent with the EPO more intensively in ICT than for other areas.

A study by FISTERA (FISTERA, 2005) looked in more detail at the patenting activity of EU countries and firms. This study used both macro (country level) and micro (firm level) data on ICT patenting. FISTERA confirmed that Europe is still behind the US and Japan in terms of ICT patenting activity, but it also emphasized that a process of catching up occurred during the 1990s, This "catch-up" was mainly driven by communication technologies and efforts in the small-medium sized European countries. Among the larger EU members ICT patenting across German, French and UK firms still grew slower than EU average.

The FISTERA study's firm level analysis puts forward a helpful characterization of the patenting behaviour of the largest European corporations. Corporate patenting in Europe is distinguished by a very high degree of concentration, with half of all patents applied for between 1976 and 2002 owned by only 33 conglomerates. An indicative list of companies includes Philips, Nokia, Ericsson, Thomson, STMicroelectronics, Siemens, Infineon and Alcatel. The firm-level analysis also reveals that the there is continuity amongst the lead patentees (i.e.: the major patenting firms are persistent over time). It also shows that European ICT patenting is heavily internationalized with European companies inventing between 30 and 70% of their patents outside of their home countries.

B. Explaining Cross-Country Differences in ICT Patenting Activity

While changes in competition affect all patenting behaviour they seem to have played an even more crucial role in the area of ICT patenting. As the OECD (2004) note some studies have highlighted the role of patent portfolios and strategic patenting behaviour for firms in both the US semi-conductor industry and the European mobile phone industry. Various changes in patenting rules may have influenced these trends. The surge in patenting in the United States that was particularly noticeable in ICT occurred after crucial court decisions lifted damage awards to plaintiffs in infringement litigation. Furthermore, an extension in subject matter (especially in the United States) was followed by a larger number of patents for software and genetic inventions. In addition, high grant rates in the United States may have attracted more applications and the surge at the EPO may have been driven in part by the significant reduction in patent fees that was made effective in July 1997.

The patentability of software-related inventions is a specific, important matter in this literature. Software has been covered by the patent system in recent years across most jurisdictions (although note the restrictions that apply to signatories of the European Patent Convention) and the number of software patents has increased as a result. However, fundamental questions still remain about the specific characteristics of software patents that require different rules to create the right incentives for innovation and knowledge diffusion.

The patentability of business methods has also been part of the debate since these are often software-based. Of course, the concern here is that low quality patents may block or impede the emerging electronic commerce sector. Software-related inventions have been patentable in the United States since 1988 on the condition that as they produce a "useful, concrete and tangible" results in addition to the traditional criteria. However, in Europe (and to some extent in Japan) software patents can only be granted if they are "sufficiently technical in nature", an approach that excludes business methods (Hall, 2003; Motohashi, 2003). The relatively permissive patentability conditions for software prevailing in the US have led to strong growth. A number of estimates indicate that USPTO software patents grew from less than 5 000 per year in 1990 to approximately 20 000 in 2000 (Hunt and Bessen, 2003).

C. The Role of Knowledge Management Applications

The rise of knowledge management applications is arguably the most pervasive feature of ICT in modern workplaces. Applications such as e-mail, groupware and databases have become ubiquitous tools. Their precise role is quantified in detailed workplace-specific studies, principally those by Aral et al (2007, 2008). These two studies use ICT and task performance data on a single, multi-establishment executive recruiting firm to discuss the relationship between technology, information flows and productivity:

- The Aral et al (2007) study measures the volume of e-mail communication, the structure of these communication networks, the use of databases, proficiency with databases and time spent on information seeking tasks. These measures are in turn linked to project and task-specific outputs.

- The main findings of Aral et al (2007) are that (i) richer communications structures (i.e.: more diverse and frequent communications) do predict wider multi-tasking behaviour and better productivity outcomes; (ii) more intense database usage is associated with higher revenue per unit of time; and (iii) workers with more diverse social networks and higher "network centrality" are even more productive at exploiting knowledge management tools.

- The later Aral et al (2008) paper focuses more tightly on team productivity and the intensity of information flows. This study in fact finds an inverted-U relationship between information flows and group productivity. That is, while higher within-team information flows (measured by the more intense usage of knowledge management applications) is associated with higher productivity at first, this relationship declines and reverses after certain threshold points.

ICT-related knowledge intensive services outside of firms are also of relevance here. A range of recent studies (Brynjolfsson, Hu and Simester 2007; Elberse and Oberholzer-Gee 2007; Ghose and Gu (2006)) have focused on the implications of falling search costs (evidenced by the rise of internet-based search tools such as Google) for the structure of firms sales. This stream of research provides quantitative evidence on the popular idea of "long tails" in markets. As search costs for consumers fall then it becomes more feasible for firms to sell niche products. Using data for a multi-channel retailer Brynjolfsson, Hu and Simester (2007) find that the sales of distribution of goods sold via the internet channel is significantly less skewed than conventional channels. This difference persists strongly even after controlling for consumer-level factors. This suggests that (i) there are significant productivity-enhancing opportunities for firms in exploiting

external knowledge intensive services and (ii) the structure of retail sales in some markets may be subject to an ongoing shift[21].

Finally, a locus for government intervention in knowledge intensive services exists with the provision and regulation of infrastructure. An example of this is ongoing developments with the evolution of spectrum. Recent technological developments have opened the possibility of obtaining an economic "digital dividend" from increased spectrum capacity. The recent Ofcom (2006) report signals a change in government policy towards spectrum. Where previously governments had followed a regulated approach that favoured a few awarded spectrum-holders policy has now moved towards a more market-led approach. The new approach is designed to promote the efficient utilisation of spectrum by as many users as possible. The economic impact of spectrum is growing with Ofcom (2006) estimating that the producer and consumer surplus due to sprectrum services in the UK grew from £28 billion in 2002 to £42 billion in 2005/06.

III. IMPACT OF ICT ON GLOBALIZATION

III.1 Technology Structure and Operation of Multinational Companies

The issues of efficiency and technological capital are closely linked in the literature on multinational firms. The literature has mainly focused on analysing whether foreign-owned firms or establishments are more efficient than similar domestically owned operations. As a result, a range of studies have focused on the role of inward investment in determining technology gaps between different types of firms. In the following sections, we first review studies which look at differences in productivity as these studies dominate the literature. We then provide a summary of the studies which have looked more specifically at the role of ICT and close this section with a discussion of future directions.

A. The Productivity Advantage of Multinationals Companies over Domestically Owned Firms

Studies in this area attempt to decompose the foreign-domestic productivity differential on the basis of the available observable characteristics. The main variables used include capital intensity, skill intensity, and the scale of operations (ie: firm size). These studies consistently find that foreign firms have higher levels of productivity than local, domestic firms. Also, this finding applies equally to firms in developing and less developed countries. We consider each group of countries in turn:

- Developing Countries: Substantial productivity advantages of MNE firms in Mexico were found by Blomström and Wolff (1994) using firm level data from the 1970s. This study also documents higher capital intensities in MNE plants. A study of Indonesian establishment data (1980 and 1991) by Sjöholm (1999) calculated differences in technology between foreign-owned and domestically-owned establishments. In this study technology is interpreted as different returns to scale and different capital intensities. Kokko, Zejan, and Tansini (2001) reported that MNEs in Uruguay in 1988 were about twice as productive as domestically owned firms. Haddad and Harrison (1993) found, for Morocco, in 1985-89, that output per worker was higher in foreign-owned firms than in domestically-owned firms.

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[21] Note that markets for consumer products such as books and music have been frequently characterised as highly concentrated "upper tail" markets were the majority of sales revenue is accounted for by a small number of best-selling items.

- Developed Countries (US): Another significant strand of the literature has focused on MNE firms in the United States. This includes Howenstine and Zeile (1994), and Doms and Jensen (1998). Howenstine and Zeile, using the combined BEA and Census establishment data for manufacturing, found that foreign-owned plants have higher labour productivity than domestically-owned ones. Doms and Jensen (1998) came to a similar conclusion but also identified an extra productivity advantage that accrued to US multinationals. Importantly, both these studies note that MNEs tend to be concentrated in high productivity industries, thereby accounting for some of the observed differentials.

- Developed Countries (UK): Finally, there is a long-standing literature on multinational activity in the UK, with a recent special focus on the characteristics of US multinationals. The first major UK studies were conducted by Dunning (1958) and Dunning and Rowan (1970). Looking at 10 industrial groups in 1950 and 1954 Dunning (1958) compared output per man-year in a sample of U.S. affiliates with that in the average U.K. firm, finding a clear productivity premium for the U.S. affiliates'. This finding was further confirmed in Dunning and Rowan (1970). A recent paper by Criscuolo and Martin (2009) explores this issue further, focusing on the distinction between US and UK MNEs in the manufacturing sector. They find that UK MNEs are less productive than US affiliates, but as productive as non-US foreign affiliates. When looking at the source of the US and MNE advantage, they find evidence in support of the fact that MNE advantage is driven by sharing superior firm level assets across plants and by cherry picking the better plants in a country. In particular, they argue that the additional superiority of US firms is entirely driven by their particular ability to take over the best British plants.

B. Multinationals Companies and ICT

In recent years, the literature has moved from merely documenting the productivity advantage of MNE firms, to looking for possible explanations for it.

- In particular, two recent studies have looked in detail at the role played by differences in ICT adoption and returns. Using UK plant level data, Bloom et al. (2007) construct a panel of data on output and inputs, including ICT and non-ICT capital and interact ICT capital with an indicator which denotes that the firm is part of a US multinational, and interpret the US dummy as being a measure of the adoption of specific organizational structures in US firms, which are complementary with ICT. They further find additional evidence supporting this hypothesis using firm level data on organizational structure for large cross-sections of US and non US multinationals operating in Europe. Their results show a positive and significant interaction between ICT and a survey measure of organizational flexibility. Furthermore, once the organizational structure-ICT interaction fully "accounts" for the higher output elasticity of ICT assets found for US multinationals.

- Crespi et al (2007) also confirm the finding that productivity is higher in US multinationals than other types of firms and that these firms are more IT intensive. They have an indicator of organizational change from the Community Innovation Survey (CIS). Consistent with Bloom et al (2007) they find that the higher productivity of US multinational's IT arises from their greater organizational flexibility.

- Abramovsky and Griffith (2006) further explore this theme, including in their analysis information on outsourcing expenditures. Their study finds that the coefficient on the

interaction between ICT and ownership is only positive and significant for the US but not for other multinationals, consistent with the evidence found by Bloom et al (2007). They further hypothesize that the ICT productivity advantage enjoyed by US MNEs is "explained" by their ability to restructure their firms' activity with higher purchases of intermediate services, which they define as outsourcing.

This evidence is consistent with the idea that multinationals have a productivity advantage in part due to their higher degree of ICT investment but (perhaps more importantly) to their organizational structures which (for US firms) is complementary to IT usage.

C. Outsourcing, Services and ICT

The outsourcing and offshoring of services is another dimension of globalisation that has received significant popular attention and is closely linked to the activities of multinationals. ICT is seen to have a major role in this new trend because of its effectiveness in lowering communication costs and allowing production tasks to be separated across space. A technical distinction needs to be made here between outsourcing and offshoring. Outsourcing represents the decision to make or buy a product or service from outside of the firm regardless of its domestic or foreign location. In contrast, offshoring explicitly concerns where the outsourcing activity, namely those locations outside of a firm's national borders (Abramovsky and Griffith 2006). So far the major studies in this literature of focused on the UK since it has specialist microdata on trade in services and outsourcing. We first discuss the stylized facts of this issue and then the role of ICT:

- Using the UK's Annual Respondents Database (ARD) Breinlich and Criscuolo (2008) put forward a number of "stylized facts" about trade in services. Their definition of service traders included firms that either import or export services outside of the UK's borders. Firstly, they found that while the service sector dominated trade in services (accounting for 80% of all traders) there was also significant services trade occurring in high-tech manufacturing. Secondly, firms engaging in services trade are typically bigger with higher productivity and a greater probability of being foreign-owned. Further to this point, while only 8% of firms were engaged in services trade they represented a large fraction of economic activity – 22.5% of total employment, 24% of turnover and 30% of value-added. Finally, there were clear differences between service importers and service exporters. The firms that focused solely on exports tended to be small with high levels of skills and high productivity. Most importantly though exporting was more common than importing with 6.9% and 3.9% of firms participating in these ways respectively[22].

- Abramovsky and Griffith (2007) provide an analysis of outsourcing activities among UK firms with a special focus on business services. They first note that business services have driven the growth of output, accounting for approximately one-third of total growth. In turn, half of this contribution was made up of business services that were delivered either through specialised, within-firm plants or through the purchase of business services from outside the firm. They found that growth in these types of business services was actually fastest during the 1984-1990 periods.

- Finally, the related study by Abramovsky and Griffith (2006) focuses specifically on the role of ICT in facilitating both outsourcing and offshoring. Again using the ARD dataset

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[22] Note that these figures include the overlap of firms that are both importers and exporters of services. .

they estimate models for the determinants of outsourcing. They find that the intensive use of ICT increases the amount of outsourced services by 13.5%. ICT has a similar role in facilitating offshoring, although it only increases the probability of offshoring by 2%[23]. Interestingly, this study also employs an instrumental variable (IV) strategy for ICT adoption, namely a UK small business tax credit for ICT. However, this IV strategy suggests that the effect of ICT in encouraging outsourcing and offshoring is under-estimated, which is contrary to the usual expectation in this empirical context[24].

D. Future Directions

There are two central challenges for the literature as it currently stands. In brief, these challenges basically relate to increasing the depth of the characteristics that are considered and extending the breadth of countries and cases studied.

- With respect to depth there is a need to measure more of the special characteristics associated with multinational firms. A current example of this approach is Bloom, Sadun and Van Reenen (2007) who use measures of organizational structure and management practices to account for the special performance of US multinationals. These characteristics can then be interacted with ICT-related variables in order to understand the link between technology usage and the internal structure of firms.

- In terms of breadth the literature on developed countries has focused mainly on the US and the UK. There is therefore a need to look at MNE productivity differentials in European economies as well as the performance of non-US multinationals. For example, it would be useful to distinguish between German, French and Scandinavian multinationals. Finally, it would be revealing to track how the same multinational performs across different countries (for example, do US multinationals perform better in the deregulated UK market than the more regulated environments of continental Europe?)

III.2 Performance and Internationalization of ICT Intensive Sectors

A key question for international comparisons of the contribution of ICT to economic performance is the role of the ICT-intensive sectors. As previous sections have outlined, the contribution of the intensive ICT-using and producing sectors is important and helps explain differences in overall productivity across countries. However, the literature is less detailed when it comes to discussing the impact of globalization on the ICT intensive sectors in different countries. The evidence so far is very interesting (particularly in terms of European trends) and suggests there may be a significant role for FDI and multinationals in driving the international convergence of ICT-intensive sectors. Van Ark and Piatkowski (2004) provide a very useful study that focuses on differences between the US, the EU15 and Central and Eastern Europe (CEE). They make the following findings:

- The employment shares of the ICT-producing industries across countries are relatively small (approximately 3-5%). The CEE countries have slightly higher shares and among them Hungary has the highest share (4.9%), possibly reflecting high rates of FDI activity.

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[23] Note here that Abramovsky and Griffith (2006) are able to measure offshoring in financial terms as the amount of services outsourced while off-shoring can only be measured as a discrete variable.
[24] Typically, it is thought that standard OLS (Ordinary Least Squares) estimate of the impact of ICT on many outcomes is upwardly biased. This is because high levels of ICT assets are typically correlated with other high productivity firm characteristics.

- Labour productivity growth rates in the ICT producing industries of the CEE countries are also high and comparable with the US and EU15. Van Ark and Piatkowski (2004) argue that this reflects massive overhauls in the ICT-producing sectors of the CEE. Hungary and the Czech Republic strand out as the best performers in this area.

- Employment shares and labour productivity growth rates for the CEE are internationally comparable in manufacturing sub-set of ICT-using industries. However, employment shares are lower in the service sub-set with Czech Republic and Poland leading performance among the CEE.

The overall conclusion of the study is that the CEE countries were able to follow a process of rapid and unexpected catch-up in the ICT-intensive sectors. Internationalization (in the form of multinational entry and FDI) is likely to have played a big role in this process. This hypothesis is particularly suited to testing using firm-level data. For example, firm-level research could test for productivity differences between foreign and domestic firms in the ICT-intensive sectors as well as tease more complex patterns of cross-country heterogeneity.

III.3 Competitiveness and ICT

The economic competitiveness of firms in the advanced OECD economies is fundamentally shaped by the international trade environment. The issues of competitiveness and ICT are linked in at least two ways.

- Firstly, to the extent that ICT is an important determinant of firm productivity it can enhance the relative competitiveness of firms in the OECD (or "North") with respect to firms in Less Developed Countries (or "South").

- Secondly, the adoption of ICT itself can be influenced by the competitive pressures created by rising import penetration. This adoption can place through two main channels, namely a "defensive innovation" response (where firms strategically move up the technology ladder to make themselves more competitive) and an outsourcing channel (where firms re-locate their low tech activities to the South and retain high tech operations in the North).

Since previous sections of this report have dealt comprehensively with of ICT's role in the production function here we focus on the latter issue of how trade affects ICT adoption and competitiveness.

The literature on trade and competitiveness has centred on the impact of trade on the labour market. Many writers have drawn a link between the two trends of increased trade and higher wage inequality, not least because basic trade theory would predict that the integration of an economy abundant in less skilled labour with a developed economy abundant in skilled labour would lead to an increase in the relative price of skill in the developed economy. Although this logic is compelling, a large body of empirical evidence emerged by the early 21st Century that strongly suggested that trade was not to blame for increasing wage inequality (e.g. Desjonqueres et al, 1999). There are many pieces of evidence including the facts that, firstly, the vast majority of the increase in the aggregate share of skilled workers has occurred within industries rather than between industries (e.g. Berman et al, 1994). Basic Heckscher-Ohlin theory suggests the opposite: because the aggregate wages of skilled workers are higher, there should be a within industry shift away from skilled workers. Secondly, wage inequality does not seem to have systematically fallen in developing countries as Heckscher-Ohlin would predict

(e.g. Berman et al, 1994). Thirdly, the within industry growth of skill demand is closely correlated to measures of technology such as computer use or R&D, but largely uncorrelated with measures of trade. Fourthly, calibrated general equilibrium models and factor content approaches find only a quantitatively small role of trade. Most authors do find an important role for skill biased technical change and/or institutions such as the minimum wage or labour unions (DiNardo, Fortrin, and Lemieux, 1996).

There are at least two major problems with the consensus, however. First, most of this work was done on data up to the mid 1990s, which largely predates the rise of behemoths like China. In 1996, for example, China only accounted for 3% of world exports. By 2006 this figure had tripled to over 9%. Secondly, an emerging line of theory has pointed to mechanisms whereby trade can affect the incentives to adopt and develop new technologies.

Thus, the finding that measure of technology such as IT are highly correlated with changing skill shares does not mean trade has no role. What may be happening is that trade is affecting technology and this is an intervening variable in changing the demand for skilled labour. Thoenig and Verdier (2003) propose a model of defensive innovation in which firms move up the technology ladder in response to competition from low wage countries. This response can occur either through the adoption of new, higher quality technologies or through the creation of new original technologies (i.e.: innovation). Recently, Grossman and Rossi-Hanberg (2007) have proposed a model of offshoring based on firms dividing production tasks across countries on the basis of relative factor prices. ICT facilitates this division of tasks across locations by facilitating the co-ordination of activities. Furthermore, the process of task fragmentation also reinforces patterns of ICT usage in the North by truncating less ICT-intensive low-skill tasks form the wage distribution. This effect is similar to that suggested in the literature on trade-related reallocations of activity (e.g.: Bernard, Redding and Schott 2008). The main idea here is that the pressure from trade-related competition (either in terms of imports or exports) leads firms to specialize in certain product lines. In turn, these product lines are associated with different levels of skill and IT intensity. In effect, this contributes to a selection process whereby low-tech firms contract and exit the market.

IV CONCLUSIONS AND SCENARIO ANALYSIS

In this final section we provide a discussion of future projections for the economic impact of ICT as well as a general conclusion on the areas covered throughout the report.

A. Projections of ICT and Productivity Growth

Jorgenson, Ho and Stiroh (2008) offer the most recent set of projections for the possible impact of ICT on productivity over the next decade. They identify a number of factors as determining the future economic role of ICT:

- The speed of ICT quality change and price declines. The most important issue here is the extent to which the trends of the late 1990s and early 2000s will be sustained over the next 10 years.

- Rates of investment in ICT. At the firm-level the question is whether firms will continue in invest in ICT or whether diminishing returns will set in. In turn, this hinges on the rate of innovation in ICT goods and the emergence of further productivity enhancing applications.

- Finally, the extent to which recent economic events represent transitory shocks or underlying trends. This is especially relevant when considering the relevance of late 1990s investment boom in ICT.

Taking these factors into account Jorgenson et al (2008) devise three scenarios for US productivity growth. In their optimistic scenario they assume that technical progress and ICT investment will continue at an average level consistent with the experience since 1995. This would results in average output growth of 3.5% and labour productivity growth of 2.8%.Their pessimistic scenario assumes that the rate of technical progress falls to the rate experienced between 1973-95. This results in a lower bound estimate of a 2.1% average growth rate for output and 1.4% per annum growth in labour productivity. Finally, their intermediate case projects output growth as continuing at 3.1% and labour productivity at 2.4%[25].

Practically, the fundamental issue in projecting the future impact of ICT lies in understanding how innovations in the development of new ICT-related goods and applications are likely to evolve. This is where qualitative scenario analysis becomes useful. The preliminary scenario analysis by RAND Europe (2008) identifies a number of plausible areas where there could be major innovations in ICT. These include: the convergence of ICT infrastructure (ie: the fusion of conventional ICT with other media technologies); human computer convergence (ie: the development of new person-related mobile applications); and the intelligent (ie: more sophisticated automated web-based applications). The importance of these trends is that that they represent potential ICT investment opportunities. Expansions of infrastructure in particular are likely to be crucial in underpinning the future rates of ICT investment that Jorgenson et al's (2008) intermediate and optimistic projections are based on.

B. Summary of Findings

This interim report has reviewed a wide range of topic related to the economic impact of ICT. The main theme of the overall literature basically relates to the rise of ICT's impact in the mid-1990s and the resulting breakdown of the "Solow paradox". The main research problem that the literature has encountered is the lack of consistent and in-depth firm microdata that is able to support the testing of multiple hypotheses. These multiple hypotheses primarily relate to the role of complementary assets in leveraging the value of ICT for firms. In turn the nature of the these complementary assets (which mainly take the form of efficient management practices and organisational structures) is also linked to other policy issues such as the performance of multinationals, the growth of outsourcing / offshoring and the spatial distribution of economic activity.

As has been discussed in the report, the next steps for research in this area include:

- A comprehensive micro-to-macro approach using firm-level data. This approach is needed to (i) isolate mechanisms and transmission channels for the impacts of ICT and (ii) breakdown regional and international differences in the role of ICT.

- A wider-ranging study of technology diffusion. Datasets measuring the adoption of detailed hardware and software technologies have only emerged recently. In particular, there is a need for international research that examines the adoption of important e-business technologies.

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25 Note that these scenarios were developed by Jorgenson et al (2008) before the onset of the international financial crisis in late 2008.

- Development of causal estimates of the impact of ICT. Compared to other area of empirical research causal estimates of ICT-related parameters virtually non-existent in this literature. Larger microeconomic datasets will maximise the opportunities to develop causal estimates (based on exogenous regional and country-level factors) and even if causal estimates remain elusive more attention needs to paid to establishing the biases that may exist with standard estimates.

- Finally, current policy discussions need to clearly delineate the expected role of ICT from other forms of "knowledge capital" such as R&D, patents, trademarks and more general intangible assets. The distinctive features of ICT as a form of knowledge capital need to be recognised before outlining policies to encourage its development.

APPENDIX A: MAIN TABLES AND FIGURES

TABLE 1: LIST OF ICT-USING AND ICT-PRODUCING INDUSTRIES

(A)	ICT-Using Industries		
UKSIC2	***Manufacturing***	**UKSIC2**	***Services***
18	Wearing Apparel	51	Wholesale Trades
22	Printing and Publishing	52	Retail Trade
29	Machinery and Equipment	71	Renting of machinery and equipment
31	Manufacture of Electrical Machinery	73	Research and Development
33	Precision and Optical Instruments		
351	Building and repair of ships and boats		
353	Aircraft and Spacecraft		
352,359	Railroad and transport Equipment		
36-37	Miscellaneous Manufacturing and Recycling		

(B)	ICT-Producing Industries		
UKSIC2	***Manufacturing***	**UKSIC2**	***Services***
30	Office Machinery	64	Communications
313	Insulated Wire	72	Computer Services and related activity
321	Electronic Valves and Tubes		
322	Telecom equipment		
323	Radio and TV Receivers		
331	Scientific Instruments		

Source: This version based on Bloom, Sadun and Van Reenen (2007), in turn based on Stiroh (2002a, 2002b). ICT intensive using sectors are defined as those sectors with above-median ICT capital flows as a proportion of total capital flows. Note that this definition of using sectors excludes industries that are also part of the ICT-producing sector.

TABLE 2: SOURCES OF US PRODUCTIVITY GROWTH, 1959-2006.

	(1) 1959-2006	(2) 1959-1973	(3) 1973-1995	(4) 1995-2000	(5) 2000-2005
Private output	3.58	4.18	3.08	4.77	3.01
Hours worked	1.44	1.36	1.59	2.07	0.51
Average labour productivity	2.14	2.82	1.49	2.7	2.5
Contribution of capital deepening	1.14	1.4	0.85	1.51	1.26
Information technology	0.43	0.21	0.4	1.01	0.58
Non-information technology	0.7	1.19	0.45	0.49	0.69
Contribution of labour quality	0.26	0.28	0.25	0.19	0.31
Total factor productivity	0.75	1.14	0.39	1.00	0.92
Information technology	0.25	0.09	0.25	0.58	0.38
Non-information technology	0.49	1.05	0.14	0.42	0.54
Share attributed to information technology	0.32	0.11	0.43	0.59	0.38

Source: Jorgenson, Ho and Stiroh (2008) Data are for the US private economy with all figures in average growth rates. Capital includes business capital and consumer durables. Information technology is defined as including computer hardware, software, and communications equipment.

TABLE 3: AVERAGE ANNUAL GROWTH RATES OF GSP, GDP PER CAPITA AND GDP PER HOUR WORKED, EU15 AND UNITED STATES, 1950-2006.

	(1) GDP	(2) GDP per capita	(3) GDP per hour worked
1950-1973			
EU-15	5.5	4.7	5.3
US	3.9	2.4	2.5
1973-1995			
EU-15	2	1.7	2.4
US	2.8	1.8	1.2
1995-2006			
EU-15	2.3	2.1	1.5
US	3.2	2.2	2.3

Source: Van Ark, O'Mahony and Timmer (2008). Estimates based on the Groningen Growth and Development Centre, Total Economy Database.

TABLE 4: MAJOR SECTOR CONTRIBUTION TO AVERAGE ANNUAL LABOUR PRODUCTIVITY GROWTH IN THE MARKET ECONOMY, 1995 2004.

	(1) Market economy	(2) ICT production	(3) Goods production	(4) Market services	(5) Reallocation
Austria	2.2	0.3	1.7	0.3	-0.1
Belgium	1.8	0.3	1	0.5	-0.1
Denmark	1.4	0.3	0.8	0.3	0
Finland	3.3	1.6	1.3	0.4	0
France	2	0.5	1.0	0.6	0
Germany	1.6	0.5	0.9	0.2	0
Italy	0.5	0.3	0.3	-0.1	0
Netherlands	2	0.4	0.6	1.1	-0.1
Spain	0.2	0.1	0.1	0.1	-0.1
United Kingdom	2.7	0.5	0.7	1.6	-0.2
European Union	1.5	0.5	0.8	0.5	-0.2
United States	3	0.9	0.7	1.8	-0.3

Source: Van Ark, O'Mahony and Timmer (2008). Calculations based on the EU KLEMS database. Column (1) is the sum of the components in columns (1)-(5). European Union aggregate refers to the ten countries covered in the table.

TABLE 5: US AND EUROPEAN STUDIES ON TECHNOLOGY ADOPTION.

Authors	Approach and Findings	Data
(A) US STUDIES		
Forman, Goldfarb and Greenstein (2003)	Participation in basic internet technologies has reached saturation level. Enhancement usage (ie: advanced e-commerce) is less widespread and reflects existing industrial patterns in technology usage. However, some new industries have emerged as leaders in adoption. Specifically, these are industries with high logistical needs such as transportation and warehousing.	US Harte-Hanks Market Intelligence database, 1998-2000.
Forman, Goldfarb and Greenstein (2005)	Adoption of basic internet usage (e-mail, web browsing) more likely in rural locations. Particularly strong relationship for technologies that facilitate inter-firm communication. Frontier internet technologies (especially those associated with within firm communication) still more likely in cities. Result for cities holds even when using controls for industry composition.	US Harte-Hanks Market Intelligence database, 1998-2000.
Forman, Goldfarb and Greenstein (2008)	Focuses on "co-invention" in the use of ICT. Defines investment in Within-Establishment Internet (WEI) as a process innovation potentially dependent on internal and external resources. Measures internal resources using programmers and external resources with local population size. External resources substitute for internal resources in cities. Internal resources have a larger marginal impact outside cities.	US Harte-Hanks Market Intelligence database, 1998-2000.
Beaudry, Doms and Lewis (2006)	Analyses pattern of technological adoption using PC intensity as a general measure.	Harte-Hanks Market Intelligence database, 1990-2000.

	Finds that cities which had high relative supplies of skilled labour (and therefore lower relative wages) adopted PCs more quickly. These cities were then the places that experienced stronger relative wage growth.	

(B) EUROPEAN STUDIES	Approach and Findings	Data
Hollenstein (2004)	Looks at adoption across extensive and intensive margins. Uses 9 measures of ICT focused mainly on computer hardware (PCs, laptops) and internet technologies. Firm size found to be an influential factor up to the threshold of 200 employees. Significant role for workplace organisation in facilitating adoption.	Cross-sectional survey of Swiss firms in 2000.
Battisti, Hollenstein, Stoneman and Worter (2005)	Distinguishes between basic and enhanced users where "enhancement" entails the use of e-commerce applications. Inter-firm diffusion is driven mainly by sector characteristics, firm size and human capital in Switzerland. In contrast variables such as organisational change, absorptive capacity and inter-firm learning effects are strong determinants in the UK.	UK and Swiss data from the Community Innovation survey (CIS) over the 1998-2000 period.
Kretschmer (2006)	Studies investments in database management systems (DBMS), operating systems (OS) and enterprise resource planning (ERP) technologies. Finds significant internal complement effects between the adoption of DBMS and associated OS and ERP.	UK Harte-Hanks Market Intelligence database, 2000-2004.
Kretschmer (2004)	Looks at determinants of OS usage in terms of vendor and upgrading decisions. Finds that larger firms are more likely to adopt specialist or niche operating systems compared to small firms.	UK Harte-Hanks Market Intelligence database, 2000-2004.

TABLE 6: CLASSIFYING KNOWLEDGE-INTENSIVE INDUSTRIES (KIS).

Broersma and Van Ark (2007) Classification
Based on NACE codes (Rev1):   72: Computer and related activities   73: Research and Development   74.1: Legal and Accounting Activities   74.2: Architectural and Engineering Consultancy   74.4: Advertising

FIGURE 1: UTILITY FUNCTIONS WITH NETWORK EFFECTS
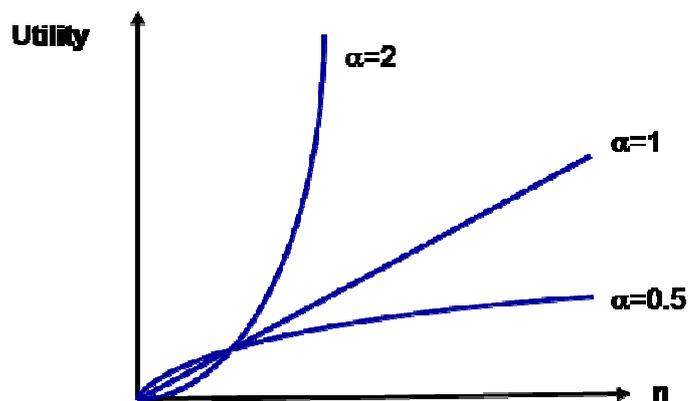
Depending on the network effect strength α, we get increasing, decreasing or constant marginal returns of network size. See section I.2, part C for detailed discussion.

APPENDIX B: LIST OF STATISTICAL SOURCES

This annexe provides a detailed list of the statistical sources to be used in this project. The annexe is divided into two sections that focus on the **main** and **complementary** datasets in turn. The main datasets represent the three principal CEP firm-level databases that will be used in the project – AMATECH, AMAPAT and the International Management Survey (IMS). The complementary datasets are the industry, regional and country-level datasets that will either be a) merged into the two main sets of microdata to provide additional variables in the regression analysis or b) used by themselves as part of self-contained descriptive or econometric analysis. In the sections below, we give a detailed review of the main datasets and a briefer summary of the complementary datasets.

A. MAIN DATASETS

(i) AMATECH

In short, AMATECH is a matched dataset that combines the Computer Intelligence Technology Database (CiTB) created by Harte-Hanks with the European Amadeus company accounts database published by Bureau Van Dijk. In the case of the US the Harte-Hanks (HH) data is matched with accounts data from Compustat, the principal source of business accounts data for listed firms in that country. We describe each of these databases below and then provide detailed notes on the matching process.

Harte-Hanks CiTDB

The Harte-Hanks CiTDB is a database of establishment-level information technology assets produced for marketing purposes. That is, Harte-Hanks collect the data in order to sell it to major ICT equipment vendors such as Dell, Microsoft and many other companies. Their data is collected for roughly 160,000 establishments across 20 European countries as well as the US. The US branch has the longest history with the company beginning its data collection activities in the mid 1980s.

Practically, the HH data is comprised of a Site File giving information on the general structural characteristics of an establishment and an Equipment File that contains information on particular lines of equipment. The contents of these files are outlined in Table B1.

In Europe, the CiTDB contains 20 countries and just under 257,000 unique establishments from 1998-2008. The majority of Western and Northern European countries have been surveyed since late 1998 and Harte-Hanks began surveying eastern European establishments in 2003. A representative cross-section of the data (for 2005) is summarized in Table B2. This table illustrates the time and industry coverage of the data across countries, with Table B3 showing the coverage of public sector establishments in more detail.

The quality and consistency of the HH CiTDB data is assured in two ways. Firstly, the fact that HH sells this data on to major firms like IBM and Cisco, who use this to target their sales efforts, exerts a strong market discipline on the data quality. If there were major discrepancies in the collected data this would rapidly be picked up by HH's clients when they placed sales calls using

the survey data, and would obviously be a severe problem   for   HH
future sales.[26] Because of this HH run extensive internal random quality checks on its own data,
enabling them to ensure high levels of data accuracy.

The second valuable feature of the CiTDB is its consistency of collection across countries. The
data for Europe is collected via a central call centre in Dublin and this ensures that all variables
are defined on an identical basis across countries. This provides some advantages over
alternative strategies such as (for example) harmonising government statistical register data
collected by independent country level survey agencies.

AMADEUS

AMADEUS is an international database of company accounts data with information on
approximately 7 million firms across all European countries. It is comprised of an **accounting
database** (with comprehensive information on financial accounts and firm characteristics) as well
as an **ownership database** describing ownership patterns at both the national ("domestic") and
international levels. Data is available from the mid-1990s with actual coverage (ie: number of
reporting firms) increasing markedly from 2001 onwards. We provide a summary of the main
variables contained in these databases in Table B4. Note that the variable list reported here
represents only the core set of variables used for economic analysis, with more specific financial
and accounting information also available in AMADEUS.

The underlying information in AMADEUS is procured from country-level data vendors (for
example, public registers of companies) and therefore the quality and depth of information can
vary across countries. In effect, the amount of information available is determined by legal filing
requirements which generally vary by the type of company within countries. However, at the
minimum AMADEUS has almost complete coverage of the major publicly listed companies in
each European country.

Panel B in Table B4 outlines the structure of the Ownership database in AMADEUS. This part of
AMADEUS is developed by a Brussels-based research team who update an archive of 21 million
ownership links from a range of direct and indirect sources[27]. This database of links allows them
to define ownership percentages and ultimate owners at the domestic and international levels.
Owners are also classified according to ten different types of organisations (including state
ownership). The cross-national coverage of the ownership data is obviously crucial for identifying
the structure of conglomerates and multinationals across countries.

Matching the CiTDB and AMADEUS

AMATECH is of course constructed from the matching of the HH CiTDB and the AMADEUS
company accounts. In the following, we document the name-matching process we have used to
match the two datasets and give a report on current progress.

The name-matching methodology used for AMATECH builds on the strategies employed in the
construction of the NBER Patents Citations file (Hall, Jaffe and Trajtenberg 2001) and the
AMAPAT database (Belenzon 2006, Abramovsky et al 2005). This process involves standardizing

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[26] HH also refunds data-purchases for any samples with error levels above 5%
[27] An indirect source in this case would be where an Ultimate Owner is inferred from a chain of ownership links recorded
by BVD rather than a direct report of a relationship between a given company A and company B.

the company-names in two datasets according to
punctuation, spelling and acronyms for company-type[28]. Matches can then be assigned a "match quality" according to how close the fit is between company name and firm characteristics are in the two datasets.

The specific process of name-matching for AMATECH has been designed as follows:

- Computer programme based string matching on the current pool company names available in AMADEUS. This pool includes all possible subsidiary companies listed in AMADEUS.
- Matching on the corporate name given in the HH CiTDB. Harte-Hanks sometimes assign a corporate name to an establishment. This name identifies the general business group that an establishment may belong to and is particularly relevant when establishment have functional information in their official name. For example, as a branch "TRIUMPH MOTORCYCLES, SHEFFIELD" would not match to AMADEUS but the corporate name "TRIUMPH MOTORCYCLES" would find a match.
- Complicated company names, characters and spelling mistakes all contribute to lowering the match rate that is feasible when employing automatic, programme-based methods. In the final stage, we "manually match" Harte-Hanks establishments to AMADEUS companies. That is, a team of research assistants conducts manual searches of the AMADEUS database and matches establishments on the basis of company name, zipcodes and industry code.

The results of the current name-matching process (as at the end of November 2008) is summarised in Table B5. Thirteen out of 20 European countries have been matched on company name, resulting in over 77,000 matched private sector establishments. The name-matching programmes have been written for the remaining seven countries and are being executed in January 2009. Matching on corporate name will also be executed in January 2009 while a full sweep of manual matching will be implemented in January-February 2009. A large pilot effort of manual matching was run in Summer 2008 using a team of four research assistants conducting matches for 5 countries. This resulted in a final 90% match rate for the manufacturing sub-sample that was chosen for matching. Typical match rates based on automatic string-matching in other projects (such as AMAPAT or the NBER Patent Citations File) range from 30-60%. The AMATECH results are in line with this and our manual matching efforts should boost the match rate to around 70%.

Another crucial issue in the name-matching process is ensuring that the resulting matches constitute a representative sample for the purposes of statistical analyses. This is done in three ways. Firstly, we compare the pattern of matches with the sampling frame of companies as represented by AMADEUS and other firm-level datasets. Secondly, we weight our statistical analysis using measures of industry and region economic activity provided in the EU KLEMS and OECD STAN databases. Finally, we define subsets of our sample where the population is well-defined. A prime example of this final approach is to condition on the population of large publicly-listed firms in our data, which is generally very well covered in AMADEUS.

(ii) AMAPAT

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[28] For example, all forms of punctuation are stripped out of name strings and company types are abbreviated to short form, i.e.: "LIMITED" becomes "LTD" and so on.

The AMAPAT dataset matches the European Patent Office   PATSTAT patents database with Bureau van Dijk's AMADEUS database. As such, AMAPAT shares many of the same methodological and data features as AMATECH. Therefore in the section below we concentrate on the features of PATSTAT and the specific variables that have been defined for AMAPAT using it. The AMAPAT database was developed by the centre for Economic Performance CEP at LSE along with researchers at the Institute for Fiscal studies. The data construction process is outlined in more depth in the papers by Belenzon (2006) and Abramovsky et al (2008).

PATSTAT is an international database produced by the EPO which contains not only all EPO patents since 1978 but also patents registered with other national statistical offices, with a major focus on significant players such as the USPTO and Japan Patent Office (JPO). Our AMAPAT work focuses on matching the EPO patents to AMADEUS accounts data from 1996 onwards[29]. The PATSTAT contains an array of complex information on patents, citations and inventors. The actual variables that we have constructed for AMAPAT are contained in Table DD below.

The choice of these variables is designed to allow many questions about innovation to be answered. Patents are counted both in terms of granted and non-granted patents with the "year" of the patent defined as the initial year of filing. Citation-related variables are specified in terms of citations received (the "knowledge outflows" from a firm to other firms and inventors) as well as citations made (the "knowledge inputs" used in the creation of a given patent or invention). These citations are broken down by their international sources. In this case we focus on the US, Germany and the "home" country as these are the most prominent cases discussed in studies of international patent-related knowledge flows. Finally, a number of variables related to the characteristics of inventors are created. Again, the focus here is on identifying inventors located in the US, Germany and the relevant "home" country but we also identify inventors in Eastern Europe because of the recent wave of R&D-intensive FDI that has flowed into this region

(iii) International Management Survey (IMS)

The final major dataset to be used in the implementation of this tender is the International Management Survey (IMS) designed and conducted by the Centre for Economic Performance (CEP). This was a major survey of firm-level management practices and organisational characteristics conducted in two waves (2004 and 2006). The IMS covers approximately 4,000 firms across Europe, the US and Asia. The survey's value lies in its ability to provide diverse and objectively-measured indicators of unobservable firm-level characteristics. The full list of countries covered by the survey includes: the US, France, Germany, Greece, Italy, Poland, Portugal, the U.K, China and Japan.

The central feature of the IMS is it use of the "double-blind" technique developed in Bloom and Van Reenen (2007) to try and obtain unbiased accurate responses to the survey questions. One part of this double-blind methodology is that managers were not told they were being scored during the telephone survey. This enabled scoring to be based on the interviewer's evaluation of the firm's actual practices, rather than their aspirations, the manager's perceptions or the interviewer's impressions. To run this "blind" scoring we introduced the exercise as an interview about management practices, using open questions (i.e. "can you tell me how you promote your

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[29] In practice, many patents filed before 1996 are also matched. However, these matches are mainly related to large continuing firms that are still alive after 1996. A problem exists with matching patents to firms that "died" before 1996 and are therefore not in the AMADEUS sampling frame.

employees"), rather than closed questions (i.e. "do you promote your employees on tenure [yes/no]?"). Furthermore, these questions target actual practices and examples, with the discussion continuing until the interviewer can make an accurate assessment of the firm's typical practices based on these examples. The second part of the "double-blind" approach relates to the interviewer – none of the interviewers are given any information about the financial performance of the firm under consideration thereby preventing them from forming any priors about management practices at the firm.

The survey targeted plant managers in firms randomly drawn from the population of all public and private firms with between 100 and 5,000 employees in the manufacturing sector. The IMS had a response rate of 45% and the response rate was uncorrelated with firm performance. The interviews took an average of 50 minutes with the interviewers running an average of 78.5 interviews each, over a median of 3 countries, allowing us to remove interviewer fixed effects. We also collected detailed information on the interview process including the interview duration, date, time of day, day of the week, and self-assessed reliability score, plus information on the interviewees' tenure in the company, tenure in the post, seniority and gender. We generally include these variables plus interviewer fixed-effects as 'noise-controls' to help control for any potential measurement error.

The IMS has been the subject of a range of papers that provide more detail on the question structure, methodology and scope of the data. Bloom and Van Reenen (2007) outline the methodology and first set of results on management practices while Bloom, Sadun and Van Reenen (2007) compare the organizational structure of firms across countries. Most recently, Bloom, Garicano, Sadun and Van Reenen (2008) analyse the links between organizational structure and the use of ICT.

B. COMPLEMENTARY DATASETS

The complementary datasets outlined in Table B7 are mainly intended to serve as extra information that can be merged into the main firm-level datasets described above. These are primarily

- The OECD STAN and EU KLEMS datasets which are particularly useful for providing industry-level measures of skills, R&D, investment, ICT capital and import penetration.
- The Eurostat R&D Scoreboard provides firm-level information on R&D expenditures for large US and European firms between 2000-1006.
- Country-level information on labour market regulation (derived from the work of Nicoletti, Scarpetta and Boylaud (20030)) will also be used. Similar information on product market regulation will also be incorporated (Conway, Janod amd Nicoletti (2005)).
- OECD Regional Data – This includes regional accounts, demographics and innovation (patents) data. Much of this data overlaps with comparable Eurostat regional data.
- World Values Survey (WVS) data from this survey has been used in the firm-level study of organizational structures by Bloom, Sadun and Van Reenen (2008)

TABLE B1: STRUCTURE OF HARTE-HANKS CiTDB DATABASE

	Variable	Notes
Site File	Siteid	Unique establishment identifier number
	Company Name	Name of the establishment as given to the HH interviewer
	Corporate Name	Name of the parent company as determined by HH interviewers and researchers
	Number of Employees	Number of employees for the establishment.
	Total Number of PCs	Number of desktop or laptop computers
	Total Number of Servers	Number of servers.
	Number of IT Employees	
	Number of IT Development Staff	
	Total Company Employees	HH estimate of total number of company employees.
	4-digit Industry Code	US Standard Industry Classification (1987)
	Zipcode	Zipcode for the location of the establishment
	Site Type	Three main site types: HQ, Branch and Semi-autonomous branch.
	Total Sites Connected by Wide Area Network	HH estimate of total number of sites connected by Wide Area Network.
Equipment File	Class	Most general equipment category: includes PCs, Systems and Servers, Networks, Operating Systems; and Application Software
	Series	Most general sub-category of equipment. For example, sub-classes for software types (ERP, email, Databases etc)
	Group	Further sub-class. For example, different categories per type of ERP (accounting, supply-chain, HRM)
	Model	Title of equipment product or model
	Manufacturer	Name of company producing the equipment line.

TABLE B2: HARTE-HANKS CiTDB SURVEY IN 2005.

	No of Establishments	Average Cell Size	No. of Industries	Average Employment	Public Sector Establishments (%)	Transport Communication (%)	Years of Coverage
Austria	6,397	50.1	595	186	8.3	6.9	1998-2007
Belgium	4,805	50.6	576	223	19.9	8.0	1998-2007
Germany	12,520	64.8	828	480	5.4	5.8	1998-2007
Spain	11,101	50.2	812	176	9.4	7.8	1998-2007
France	27,376	192.6	907	225	16.4	7.2	1998-2007
Great Britain	16,224	76.5	892	344	9.1	6.6	1998-2007
Ireland	1,816	26.4	379	192	4.7	6.6	1998-2007
Italy	8,567	58.3	769	205	10.7	7.5	1998-2007
Netherlands	12,521	79.0	746	225	21.3	7.6	1998-2007
Portugal	687	12.0	260	274	17.6	5.5	1998-2007
Switzerland	6,807	49.0	593	170	10.4	6.7	1998-2007
(B) Scandinavia							
Finland	3,916	31.9	489	201	8.8	9.7	1998-2007
Norway	2,861	72.8	467	194	29.8	8.2	1998-2007
Denmark	5,036	31.6	611	136	13.6	7.0	1998-2007
Sweden	6,968	102.4	627	209	14.3	6.4	1998-2007
(C) Eastern Europe							
Czech Republic	1,624	13.2	376	255	9.7	8.7	2003-2007
Hungary	2,925	24.4	488	131	1.9	11.0	2003-2007
Poland	4,647	27.8	583	286	4.4	10.8	2003-2007
Slovakia	864	8.6	288	246	6.8	6.6	2003-2007

Notes: Based on 2005 wave of Harte-Hanks CiTDB Survey. Total of 138,432 establishments across 19 countries. Public Sector Establishments defined as those belonging to the 2-digit SIC classifications 80 (Health Services); 82 (Education Services); 83 (Social Services); 84 (Museums and Gardens); and 91-97 (Public Administration). Transport and Communication Establishments defined as those belonging to the 2-digit SIC classifications 40-49.

TABLE B3: NUMBER OF PUBLIC SECTOR ESTABLISHMENTS BY SIC2 INDUSTRY,
HH CiTDB SURVEY 2005.

SIC2	Industry Description	Number of Establishments
80	Health Services	4,202
82	Educational Services	3,409
83	Social Services	1,014
84	Museums, Galleries & Gardens	126
91	Executive, Legislature & General Government	5,148
92	Justice, Public Order, and Safety	435
93	Public Finance and Taxation	357
94	Administration of Human Resource Programs	850
95	Administration of Environmental Quality &Housing Programs	883
96	Administration of Economic Programs	466
97	National Security and International Affairs	172

Notes: Based on 2005 wave of Harte-Hanks CiTDB Survey. Total of 17,062 establishments across 19 countries

Enterprise LSE

TABLE B4: STRUCTURE OF AMADEUS COMPANY ACCOUNTS DATABASE.

	Variable	Notes
Accounting Database	**Financial Accounts**	
	Operating Revenue	Sales or turnover measure
	Material Costs	Expenditure on materials
	Number of Employees	Headcount of Employees
	Tangible Fixed Assets	
	Gross Profit	Profit before taxes
	Depreciation	Depreciation on assets
	Company Characteristics	
	BVD Identifier	Unique establishment identifier number
	US SIC code (core and primary)	US standard industry code; core = 3-digit, primary =4-digit
	NACE SIC code (core and primary)	Europe-wide standard industry code
	National SIC code (core and primary)	Country-specific standard industry code
	Address and Zipcode	
	Region/ City	
	Publicly Listed	Flag for public, stock market listed companies
	Consolidated Accounts	Consolidated accounts aggregate financial information for all company subsidiaries.
Ownership Database		
	Percentage Direct Ownership	Ownership relationship that flows directly from company A to company B
	Percentage Indirect Ownership	Ownership relationship from company A to company C (i.e.: mediated by ownership link between company A and company B)
	Type of Shareholder or Owner	Type include: Industrial company, Bank, Financial company; Mutual or Pension Fund, Public Authorities / Governments; Foundations, Individuals or Families; Employees/Managers; Self ownership; Private equity firms.
	Domestic Ultimate Owner	Shareholder with the highest direct or total ownership percentage in the local country
	Global Ultimate Owner	Shareholder with the highest direct or total ownership percentage internationally

Notes: Source is BVD Ownership Database documentation. Accounting variables listed in this table are a sub-set of the main variables for use in economic analysis and estimation. See BVD Online for a full list of all available Profit and Loss and Balance Sheet information

TABLE B5: AMATECH NAME MATCHES, NOVEMBER 2008.

Country Code	Country	Number of Matches	Total Establishments	Match Rate
AT	Austria	3,718	9,386	0.396
DE	Germany	10,659	30,390	0.351
DK	Denmark	2,198	4,992	0.440
ES	Spain	5,701	13,087	0.436
FI	Finland	1,602	3,878	0.413
FR	France	10,087	24,913	0.405
GB	Great Britain	12,123	23,506	0.516
IT	Italy	6,020	12,409	0.485
NL	Netherlands	15,541	35,290	0.440
NO	Norway	1,148	2,907	0.395
PO	Poland	1,714	4,477	0.383
SE	Sweden	3,224	6,384	0.505
CH	Switzerland	3,809	9,897	0.385
Total		77,544	181,516	0.427

Notes: Match based on first step automatic name matching, current as at November 2008. Excludes all public sector establishments.

TABLE B6: MAIN PATENT-RELATED VARIABLES IN AMAPAT.

Variable	Notes
(A) Patent Counts	
Patent Count (Granted)	Based on filing date for patent
Patent Count (applications)	Counts non-granted applications and patents still under review.
(B) Technology Classes	
Number of Technology Classes	Number of IPC technology classes covered by the patents in the firm-year cell.
(B) Knowledge Outflows – Citations received	
- Number of Citations Received	Counts all citations accruing to the patents appearing in each firm-year cell.
- Number of Citations Received from US Patents	Counts citations received from patents featuring a US-based main applicant
- Number of Citations Received from German Patents	Counts citations received from patents featuring a German-based main applicant
- Number of Citations Received from Home-Country Patents	Counts citations received from patents featuring an applicant in the same country as the inventing firm
(C)Knowledge Inputs – Citations made to other patents	
- Number of Citations Made	Number of citations made to all other patents
- Number of Citations Made to US Patents	Number of citations made to US patents
- Number of Citations Made to German Patents	Number of citations made to German patents
Number of Citations Made to Home Country Patents	Number of citations made to applicants in the same country as the inventing firm.
(D) Inventor Information	
- Number of Inventors	Number of inventors assigned to the patent
- Number of Inventors Located in US.	Number of inventors located in the US
- Number of Inventors Located in Germany	Number of inventors located in the Germany
- Number of Inventors in Eastern Europe	Number of inventors located in Eastern Europe
- Number of Inventors in Home Country	Number of inventors located in the same country as the inventing firm

Notes: This table represents the variables constructed for the firm-year AMAPAT dataset. Patent counts are defined for firm-year cells with citations counted as all "forward citations" up to 2007.

TABLE B7: DESCRIPTION OF COMPLEMENTARY DATASETS

Dataset	Description	Role
Eurostat R&D Scoreboard	Firm-level R&D intensity information for large European and US companies.	Merged into AMATECH and AMAPAT to provide firm-level R&D controls.
EU KLEMS	International Industry Level accounts dataset.	(1) Provide extra industry level covariates in firm-level regressions (2) Used to weight firm-level regressions (3) Data for industry-level regressions
OECD STAN	International Industry Level accounts dataset	(1) Provide extra industry level covariates in firm-level regressions (2) Used to weight firm-level regressions (3) Data for industry-level regressions
OECD Employment Protection Legislation	Country-level indicators for different aspects of employment protection. Available for 1998 and 2003	Extra covariate in firm-level regressions (interacted with industry characteristics)
OECD Product Market Regulation	Country-level indicators for product market regulation, with some information on specific sectors (e.g.: retail, utilities)	Extra covariate in firm-level regressions (interacted with industry characteristics)
OECD Regional Data	Large and Small Regions, Labour market statistics, Regional Accounts	(1) Provide region-level covariates in firm-level regressions (2) Used as the basis of regional spillover interaction terms
World Values Survey	International microdata with a special focus on opinions, beliefs and values.	Extra covariate in firm-level regressions (See Bloom, Sadun and Van Reenen (2008))
Eurostat Survey of ICT Usage and E-Commerce	Survey data on ICT and E-Commerce for European households and businesses.	Background descriptive statistics
Eurostat Survey of E-Government	Survey data on E-government services.	Background descriptive statistics

TABLE C1: MACROECONOMIC STUDIES OF ICT AND PRODUCTIVITY.

Authors	Country and level of aggregation	Data	Measure of ICT	Method	Key results
Gordon (2000)	US, 1972-99	Uses data developed by Oliner and Sichel (2000).	Distinguishes between computer hardware, software and communication equipment. Productive stocks are calculated for hardware using detailed BLS equipment data. From).	Builds on previous growth accounting exercises, decomposing output/hour according to (i) cyclical effects; (ii) contribution of IT-producing sector.	Finds no evidence of structural acceleration in productivity during 1995-9 after accounting for cyclical and IT producing sector effects.
Gordon (2003)	US, 1972-2002	Business cycle analysis uses quarterly BLS data on 4 sectors: non-farm private business, manufacturing, durables, non-durables.	Focus on Oliner and Sichel (2000) results.	Performs further business cycle decomposition Main argument is that role of IT investment is exaggerated. Stresses that productivity gains have occurred but source lies outside of IT alone.	Main arguments: (1) Results such as Oliner and Sichel (2000) assume an unrealistic instant pay-off to IT investment. (2) Micro evidence in retail suggests productivity revival is uneven – concentrated in new establishments only. (3) Cross-state comparisons do not exhibit the expected relationship between IT intensity and state productivity.
Gust and Marquez (2004)	13 OECD countries, 1993-2000	OECD national data and regulations database	2 measures: (a) Share of IT producing sectors in GDP (OECD); (b) IT expenditure: GDP ratio (World IT Service Alliance)	Models labour productivity growth as a function of IT and other controls (e.g. employment population ratio, country fixed effects). Also look at IT investment equations	IT production and (to a lesser extent) IT expenditure are associated with higher productivity growth. Labour and start-up regulation significantly retards IT (although no controls for country fixed effects)
Jorgenson (2005)	G7 Economies (Canada, France, Germany, Italy, Japan, UK, US)	van Ark *et al.* (2002) for Europe BEA and BLS (US) Statistics Canada	Investment in IT hardware and software Uses internationally consistent prices following Schreyer (2000) and Wyckoff (1995)	Detailed growth accounting analysis of input per capita, output per capita and TFP. 'Capital quality' represented by capital input: capital stock ratio.	Late 1990s surge in IT capital investment is found across the G7. Declining contributions of non-IT capital offset effect of IT surge in Japan, France and

		Jorgenson and Motohashi (2005) (Japan)			Germany.
Jorgenson, Ho and Stiroh (2008)	US, 1949-2006.	BEA and BLS	Investment in ICT hardware and software	Updates earlier studies using growth accounting analysis of input per capita, output per capita and TFP	Breaks the post-1995 productivity acceleration into two phases with the 2000 as the breakpoint.
Oliner and Sichel (1994)	US, 1970-92	BEA and BLS	Computer hardware and software	Examines reasons for the (then) IT productivity puzzle. Addresses assumptions regarding returns to IT, measurement and focus on hardware alone.	Main conclusion is that puzzle is 'more apparent than real': level of IT capital is simply low (2% total capital circa 1993). Robust result even when varying assumptions on returns to IT and measurement.
Oliner and Sichel (2000)	US, 1972-99	BEA and BLS	Distinguishes between computer hardware, software and communication equipment. Productive stocks are calculated for hardware using detailed BLS equipment data.	Detailed growth accounting. Breaks down contribution to output growth according to income shares and input growth rates.	IT capital is 1.1% of the 4.8% output growth rate during 1996-9. By comparison, earlier periods (1974-95) show IT contribution as 0.5-0.6%. IT producing sectors also experienced acceleration at 40% of total MFP growth for 1996-9.
Oliner and Sichel (2002)	US, 1974-2001	BEA and BLS	As above.	Extends results from Oliner and Sichel (2000) to 2001. Uses multi-sector growth model to assess sustainability of IT-driven growth and make projections.	Earlier results on contribution of IT using and producing sectors still valid despite the dot.com bubble. Model projections of 2-2.75% labour productivity growth/year over the next decade.

| Oulton (2002) | UK, 1979-98 | ONS data for national accounts.

Note US producer price indices (adjusted for exchange rates) used to value ICT.

Value of software adjusted upwards. | Computers, software, telecoms equipment, semi-conductors. | Growth accounting but with important modifications with respect to measurement (e.g. use of US PPI, valuation of software). | Revised approach suggests GDP growth is underestimated, e.g. growth in 1989-98 periods is 0.3% greater following the 'high' software approach.

ICT contribution to GDP growth increased from 13.5% in 1979-89 to 20.7% in 1989-98.

ICT contributed 55% of capital deepening during 1989-98 and 90% from 1994-8. |
| Wolff (2002) | US industries, 1960-90 | National Income and Product Accounts (NIPA) (employee compensation).

BEA (tangible wealth).

Census of Population (education) | Stock of Office, Computing and Accounting (OCA) equipment category in BEA capital data. | TFP and labour productivity equations, regressions relating computer investment to structural change | No evidence of positive links between computer investment and TFP or labour productivity growth.

Computer investment positively associated with occupational and industry restructuring. |

TABLE C2: INDUSTRY-LEVEL STUDIES OF ICT AND PRODUCTIVITY

Authors	Country and level of aggregation	Data	Measure of ICT	Method	Key Results
Basu et al. (2003) (see below for UK)	US	Manufacturing and Services, 1977-2000 (Some only since 1987), BLS, BEA.	US data from the BLS capital input data disaggregated by industry. Among equipment, BLS provides additional detail for information processing equipment and software (IPES). IPES is composed of 4 broad classes of assets: computers and related equipment, software, communications equipment, other IPES equipment.	Objective to test the GPT hypothesis by focus on potential presence of unmeasured complementary investments and presence of TFP gains amongst IT-using and non-using sectors.	ICT capital growth negatively correlated with TFP growth in late 1990s (consistent with simple model of unmeasured complementary investments).
Basu et al. (2003)	UK	34 industries, 1979-2000. (BE, Bank of England dataset).	ICT capital services derived using US methodology (Jorgenson and Stiroh 2000a, b) hence geometric, depreciation rate with US prices converted to sterling. Note software levels multiplied by three.	See above.	ICT capital services growth positively correlated with TFP. However, ICT investment positively correlated with TFP suggesting scope for the GPT hypothesis (given shorter lags in the UK).
Berndt and Morrison (1995)	US industries	2-digit manufacturing,	Define high tech capital as aggregate of office and IT	Aim is to examine diffusion and impact of high-tech	Limited evidence of positive relationship between profitability and share of high-tech

		1968-86	capital.	capital	capital.
			Covers 4 asset codes OCAM including: office and computing machinery; communications equipment; scientific and engineering instruments and photocopy equipment).	Labour productivity and profitability equations.	High-tech capital share negatively correlated with MFP. Greater levels of high-tech capital associated with superior economic performance However, increasing rates of such capital within industries not necessarily associated with improved performance.
Chun and Nadiri (2002)	US 4-digit industry	NBER-CES Manufacturing Industry Database	Decomposes TFP growth in 4 computer industries	Uses hedonic price information to separate out TFP growth due to product innovation (i.e. quality improvements); process innovation (i.e. technological efficiency improvements) and economies of scale.	Computer industry TFP growth explained by product innovation (30%); process innovation (50%) and economies of scale (20%). Increasing role for product innovation during late 1990s. Computer industry contribution to aggregate productivity growth estimated to be 1/3 of total TFP growth.
Crepon and Heckle (2002)	France	Firm data aggregated up to 2-digit sectoral and macro level, 1987-98	OCAM - office, computing and accounting machinery. Comes from tax declarations of 300,000 French firms (outside financial sector).	Growth accounting exercise	ICT contributes 0.7%/annum on average (0.4% from production of ICT, 0.3% from capital deepening). Av. value added growth 1987-98 is 2.6%/annum. Share of ICT capital much higher than suggested by French National Accounts (Cette, Mairesse, and Kocoglu, 2005)
O'Mahony and Vecchi (2003)	UK US industries	UK (24), US (31) 1976-2000	ICT capital stock built from supply and use tables.	TFP regressions including heterogeneous panel estimates	LR effect of ICT above its factor share.
Oulton and Srinivasan (2005)	UK industries	34 industries 1970-2000 (BE Dataset)	ICT capital stock built from supply and use tables	Growth accounting, TFP and labour productivity regressions	ICT capital deepening has positive and significant effect post 1990 (accounts for large proportion of 1990s productivity growth)
Stiroh (2004)	US 2-digit (61 industries)	BEA Industry data on output, investment and capital stocks.	(1) IT capital stock comprising computer hardware and software. (2) Telecoms equipment as	(1) Meta-analyses of 20 existing studies based on methods, type of data and resulting IT elasticity. (2) 'Full disclosure' regression	(1) IT elasticity predictable based on approach and estimation method. Mean estimates include 0.042 (value-added) and 0.066 (gross output). (2) BEA data regressions indicate IT

			separate category of capital.	analysis of BEA data using many alternative approaches and reporting all findings.	elasticities fall as estimation moves from levels to methods accounting for unobservables. System GMM provides the most sensible estimates (0.05 IT elasticity).
Stiroh (2002a)	61 US 2-digit industries (1987-2000) 49 US 2-digit industries (1977-2000)	BEA data on industry gross output, labour input and intermediate input. BEA Tangible Wealth Survey used to build capital stocks.	IT capital built up from wealth stocks on computer hardware (8 types); software (3 types); and communication equipment. Capital Service Flow measure constructed by aggregating individual capital stocks using asset-specific prices.	Uses pre-1995 IT intensity (both discrete and continuous measures) to assess whether acceleration argument for IT-using industries is valid. Decomposes labour productivity growth according to 3 sectors: IT-producing and IT using industries, and those 'isolated' from IT.	Pre-1995 IT intensity related to patterns of acceleration for discrete and continuous measures. Acceleration for IT intensive industries approximately 2% more than other industries. Decomposition finds that IT-using industries contribute 0.83% of total acceleration with IT-producing industries accounting for 0.17%. Isolated industries made a -0.21% contribution.
Stiroh (2002b)	US 2-digit Manufacturing (18 industries *15 years)	BLS multifactor productivity database for manufacturing (18 industries from 1984-1999)	ICT capital including total value of hardware, software and telecommunications equipment. Computer capital defined as hardware and software assets only.	Tests a key spillover hypothesis: that ICT impacts on TFP if network effects or externalities are present. Uses traditional difference-in-difference and traditional Labour Productivity and TFP regressions to test above hypothesis.	Finds some positive effects of ICT on average labour productivity but not TFP. Telecommunications capital has a negative association with productivity. In general, no strong evidence of spillover-type effects of ICT on productivity.
Van Ark *et al.* (2004)	12 EU countries and US (EU countries include Austria, Denmark, Finland, France, Germany, Ireland, Italy, Netherlands, Portugal, Spain, Sweden, UK)	Manufacturing and Services, 1980-2000 (Using input-output tables)	(1) Broad definition of ICT as comprising the whole category of office and computer equipment - including peripherals (2) Separate investment series on ICT investments used where available (applies to most assets for Denmark, France, Netherlands, Italy, UK, only to specific assets for	Concentrates on building comparable ICT investment and ICT capital data across EU and US then employs standard growth accounting and labour productivity equations.	Similar growth rates ICT real capital formation and capital services for US and EU. Investment patterns similar – office equipment grew strongly in the 1980s and from the late 1990s. Growth of communication equipment and software accelerated after 1995 (more so in the US). ICT investment share levels lower in the EU - 2/3 of US level throughout the period.

			Germany and Spain). (3) Used a Commodity Flow Method to fill gaps. This supply side method first computes total amount of ICT commodities available in a specific year as value of total ICT production less ICT exports plus ICT imports.		Relative contribution of ICT to EU labour productivity growth close to US but slowdown in EU growth reduces the absolute contribution. Stronger TFP effects for ICT-producing sectors in the US during the 1990s.
van Ark and Inklaar (2005)	US and European industries (France, Germany, Netherlands, UK)	60 industries, 1987-2004. Specially constructed GGDC dataset.	Investment series for different types of IT-related capital expenditure.	Growth accounting equations for macro-level data. Labour productivity equations for industry data ('shift-share' approach following Stiroh (2002b). TFP equation to test for spillovers.	Lower IT-contribution to EU growth has continued through early 2000s. US-EU differential increased following strong labour productivity gains in US market services (i.e. non-government sector). No evidence of IT spillovers to TFP. Hypothesis of U-shaped IT returns pattern: initial 'hard savings' followed by experimentation period then 'soft savings' as capital complementarities develop.
Van Ark, O'Mahony and Timmer (2008)	US and European industry data	EU KLEMS dataset, 1950-2004	ICT investment series for ICT capital expenditure	Updated growth accounting analysis to 2004	Confirms US strength in ICT producing sector and market services relative to the EU

TABLE C3: FIRM-LEVEL STUDIES OF ICT AND PRODUCTIVITY

Authors	Country and level of aggregation	Data	Measure of ICT	Method	Key Results
Atrostic and Nguyen (2005)	US establishments	Computer Network Use Supplement (CNUS) of the 1999 Annual Survey of Manufactures (ASM). Approximately 30,000 plants.	Discrete indicator of whether establishment uses a computer network.	3 factor production function (incorporating materials). Endogeneity of networks addressed by explaining network presence as function of past performance (2SLS).	OLS indicates that labour productivity is 3.7% higher for network-using establishments. 2SLS indicates a 7.2% effect. Lower productivity in earlier periods associated with networks. Interpreted as evidence that establishments may use networks to catch up.
Black and Lynch (2001)	US establishments	Educational Quality of the Workforce – National Employers Survey (EQW-NES) matched with Longitudinal Research Database (LRD) 638 establishments in manufacturing, 1987-1993	Proportion of non-managers within establishment using computers. Many controls for workplace practices and characteristics (education, union presence) to account for complementarities.	Cross-sectional Cobb-Douglas production function. 2-step fixed effects approach (i.e. second stage involves regressing firm effects on a set of explanatory variables).	IT variable significant and positive in cross-sectional production function. IT significant in 2-step within estimator, but not GMM version.
Black and Lynch (2004)	US establishments	1993 and 1997 waves of the EQW-NES. Panel of 766 establishments (again matched with LRD). 284 establishments in the balanced panel.	Proportion of non-managers within establishment using computers. Again, controls for other (complementary) workplace practices and characteristics.	Cross-sectional Cobb-Douglas production functions for 1997 wave. Includes interaction effects in production functions. Production functions with fixed effects (for balanced panel). Uses estimates in a decomposition of MFP	IT variable significant and positive in cross-sectional production function. Interaction terms of IT variable with workplace practices and characteristics not significant. IT variable significant in fixed effect model for balanced panel. Workplace innovation makes 1.4% contribution to MFP growth (approximately 89% of total MFP

				growth (benchmarked against BLS estimates).	growth)
Bloom, Sadun, and Van Reenen (2008)	British establishments 1995-2004 (unbalanced panel)	7,000 establishments	IT capital constructed from 3 ONS surveys (FAR, Quarterly Capital expenditure Survey, BSCI). PIM	Estimation of panel production functions and TFP regressions. Compare OLS, Within Groups, GMM and OP.	IT significant impact on productivity. Effect greater for US than non-US multinationals or domestic firms. US effect also stronger in IT intensive industries.
Bloom, Draco, Kretschmer and Van Reenen. (2005)	Britain (1994-2004),	About 3,000 firms in 1994-2004	Constructed using Harte-Hanks hardware and software data (recorded at business site level). Measures include: (i) Value of IT hardware (ii) PCs/employee	Production functions estimated by OLS, within groups and GMM. Tests for heterogeneity of IT impact across different firm characteristics (e.g. size, sector, and time period). Tests for spillovers at the regional and industry level. Reduced form investment models.	Significant and positive effect of IT on productivity (elasticity with respect to output 0.035 on within-groups specification) No evidence of IT spillovers at industry or region level.
Bresnahan, Brynjolfsson, and Hitt (2002)	US firms across all types of industries.	331 firms (NB survey asked managers about characteristics at level of the 'typical establishment')	ICT capital calculated using CII data on firm computer hardware inventories only. Author's (cross-sectional) survey of organizational practices and skills circa 1995-6. Compustat accounts information.	Correlation analysis of relationship between potential complementary inputs. Input choice functions. Production functions with interaction terms.	Complements (IT, organization and skills) significantly and positively co-vary Skills and organization significant as determinants of IT demand. IT-Skill and IT-Organization interaction variables significant in production function.
Brynjolfsson, Hitt,	US firms	1987-97	CII measure of the market value of	Estimates market value	Key organizational characteristics

and Yang (2002)		Compustat firms matched with CII data and author's (cross-sectional) organizational practices survey. Final sample features 272 firms with matched data and 2,097 observations in total.	computer equipment at a firm (calculated based on replacement cost).	equation focusing on how IT and organizational practices represent intangible assets. OLS, Least absolute deviations, Fixed and Random Effects estimation of market value equation. Also, use long difference specification. Nonparametric plot of relationship between organization, ICT and market value.	correlated with ICT capital but not physical capital. ICT capital associated with higher market value. Interaction term between organization and ICT significant – firms with combinations of ICT and good organizational practices have the highest market value.
Brynjolfsson and Hitt (2003)	US firms	527 large Compustat firms 1987-94	Computer capital stock CII (Harte Hanks) value of total IT stock; IDG (firms stated value of mainframes plus no. PCs)	OLS, short and long differences. Production function and TFP equation	In long differences IT coefficient above IT capital share in revenue
Dewan and Min (1997)	US firms	Computerworld data matched to Compustat. 1,131 observations (unbalanced) with maximum of 304 different firms observed in a single year 1988-92.	Market value of computer hardware and labour expenses for IT staff.	CES-Translog production functions.	Some evidence of excess returns to IT capital.
Forth and Mason (2003)	UK firms	1997-9 International Benchmarking Survey; 308 firms c. 900 observations	Categorical indicators of different types of ICT	OLS and IV estimation	Generally positive impact; interactions with skill shortages
Gilchrist, Gurbaxani, and Town (2003)	US firms, 1986-1993	CII matched to Compustat. Unbalanced panel of 580 firms.	IT hardware value. PCs/employee.	GMM estimation of production function. Regressions of Solow residual on inputs.	IT coefficient approximately equal to cost share; PCs have additional impact in durable goods sectors. Growth of PCs significant in Solow residual regression, also with additional impact in the durable

				goods sector.
Greenan, Mairesse, and Topiol-Bensaid (2001)	French firms, 1986-94	SUSE (System of Unified Statistics on Enterprises) and ESE (Employment Structure Survey) Approximately 3,000 manufacturing firms and 2,500 in services.	Value of office and computing equipment No. of specialized workers (computer, electronics, research and analysis staff),	Mainly examines correlations between IT, R&D and skills. Some production function estimation.	IT effect is not significant when firm fixed effects are included. Share of blue-collar workers falls with increase in IT (for all indicators).
Greenan and Mairesse (1996)	French firms, 1987-93	TOTTO (specialized survey of techniques and organization of work) matched to INSEE firm database for 1987, 1991, 1993. Approximately 3,000 observations/year.	No. employees using computers at work (calculated from sample)	OLS Cobb-Douglas production function, no fixed effects	IT coefficient stable across models for all 3 years. Coefficient of approximately 0.20.
Gretton, Gali, and Parham (2004)	Australian firms	Australian Business Longitudinal Study Panel of three years 1988-9; 1993-4; 1998-9 Sample sizes not clearly stated.	Binary indicator and duration dummies	OLS Productivity growth equation. Controls include lagged level of productivity, capital growth. Separately for 8 sectors	IT positive in most, specifications, significant in only 2 specifications
Haltiwanger, Jarmin, and Schank (2003)	US and Germany	Matched ASM and CNUS for the US, 1999-2000. 22,000 observations. IAB manufacturing sector panel for Germany, 2000-1. 3,500 observations used in regression analysis.	Total investment in computers and peripheral equipment (US). Total investment in information and communication technology in previous business year (Germany) Proportion of employees with internet access (US and Germany)	Compare the productivity outcomes for similar IT intensive firms in both countries. High IT intensity defined by whether firms are in the top 25% viz IT investment and internet access. Assumes that the most IT intense firms have a propensity to 'change technologies'.	IT-intensive US firms exhibit greater productivity dispersion, particularly amongst younger businesses.
Hempell (2005)	German and Dutch firms	1998 CIS (but with lags as IVs); distribution and business services; Netherlands 972; Germany 995	ICT expenditure converted into a stock	GMM-SYS (but instruments appear invalid as Sargan-Hansen test rejects)	Significant ICT effect; many complementarities

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Hendel (1999)	US establishments	Comtec survey of 7,895 establishments (Conducted 1994 and 1998). Note studies only 240 banking and insurance establishments from 1988 survey. PC price and characteristics data (used by Berndt and Griliches 1993).	Detailed information PC hardware, including brand, type, quality.	Explicit model of establishment-level demand for differentiated types of PCs. Based on buyers making multiple discrete choices. Task-based model of why establishments choose different types of computer equipment.	Estimated return on PC investment calculated as 92%. 10% increase in performance-to-price ratio for microprocessors estimated to raise user surplus by 2.2%.
Lehr and Lichtenberg (1998)	US govt agencies, 1987-92.	BLS Productivity Measurement Program (Data on agency output and productivity). CII 44 agencies in matched data.	Replacement value of computer capital (via CII).	Production functions based on BLS estimates of the output of government services (44 agencies).	Excess returns to computer capital (with 0.061 co-efficient on computer capital compared to 0.014 share of IT capital in total cost).
Lehr and Lichtenberg (1999)	US 1977-93	Enterprise Survey (Census Bureau) Auxiliary Establishment Survey Compustat CII Matched sample includes 500 firms.	Replacement value of computer capital (via CII) Investment in computer equipment (Census Bureau)	Production function regressions, including terms for specific types of equipment. Inventory regressions (i.e.: test whether computers facilitate just-in-time style production strategies).	Excess returns to computer capital still found after including firm fixed effects. These returns peak in 1986-7. Negative association between computer capital and inventories.
Lichtenberg (1995)	US	190 to 450 firms	Computer and non-computer capital stock, ICT and non-ICT labour	OLS, no IV or fixed effects	In long differences IT coefficient above cost share
Matteucci et al. (2005)	Germany, Italy and UK	Germany IAB 3,168 observations 1997-2000 Italy 'Capitalia' manufacturing	Lagged ICT investments plus instruments based on firm training patterns (Germany) Single year of ICT investment information	Regressing firm fixed effects on various characteristics to explain determinants of productivity.	Significant effect of ICT in manufacturing but not services.

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		firms 1995-2000 3,918 observations (unbalanced) and 1,119 (balanced) ABI linked with 2001 ONS E-commerce survey 2,422 observations.	Duration of internet access at firm and proportion of workers using a PC	TFP Equation Cross-sectional Cobb-Douglas production function	Weakly significant effect of ICT (10% level). Significant impact for PCs/worker in service sector
Wilson (2004)	US 1998	1998 ACES matched with Compustat firms 3,000 firms in matched sample.	Total Computer and Peripheral Equipment Investment as measured in ACES	Looks at the effects of different capital types on variously defined measures of TFP. Uses to interaction effects to examine complementarities and substitutability between capital types. Calculates marginal products for different capital types.	Positive effects of computer capital on TFP. 'High-tech' capital complementary with 'low-tech' capital. Different types of capital are substitutable within their technology class (i.e. high-tech vs. low-tech). Marginal products for computers, communication equipment and software are higher than those suggested by BLS rental prices.

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