The Economic Impact of ICT
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ABOUT THIS REPORT

This is the third and final report for the EU Commission's "Economic Impact of ICT" project. We would like to thank the Commission for their comments on earlier drafts as well as financial support for this project.

The second interim report detailed the methodological aspects of the projects while the first contains a literature review. The present report is designed to be a self-contained document. However, the first two reports have been attached as Annexe I and Annexe II respectively for reference.

In this report, the "abstract" section provides a condensed summary of the main findings of the report. These findings are reported in two sections firstly relating to the main research based on cross-country, firm-level data (covering the core topics of productivity, innovation and globalisation) and then secondly to studies of other topics that used specialised datasets or methodologies (in particular the sections on prices, spatial concentration and work-life balance).

The following executive summary provides a more detailed review. This summary first reports on the background and methodology of the report and then gives empirical findings following the structure set out in the abstract. The executive summary ends with separate sections discussing policy implications, future scenarios, research innovations and areas for future research.

Finally, we would also like to acknowledge the assistance of staff who helped in the production of the report: Meli Cardona; Linda Cleavely, Christian Fons-Rosen, Ferdi Mahr, Michela Meghnagi and Kati Szemeredi.

ABSTRACT

This report provides new research on the economic impact of ICT. The major impetus for the research is the post-1995 “productivity miracle” whereby US productivity growth accelerated, led by the contribution of ICT to capital deepening and total factor productivity growth. The economies of the EU did not experience the same type of acceleration. As a result, while only a 1.8% gap between the levels of US and EU output per worker existed in 1995 this gap grew to 9.8% by 2004[1]. A substantial part of this gap was due to stronger productivity growth in the US ICT production and market service sectors. This contrast in performance created a major economic puzzle insofar that the European economies experienced the same types of sharp falls in the prices of ICT producer goods that stimulated ICT investment and productivity in the US. Practically, this implied that there were barriers to the economic exploitation of ICT present in Europe.

The increased economic importance of ICT therefore raised new questions for governments regarding the best policy frameworks to adopt for encouraging both ICT investment and ICT-led innovation. The rapid diffusion of ICT in the 1990s also introduced new policy issues for consideration, such as the effect of ICT on the distribution of economic activity and the influence of ICT on producer and retail prices.

Productivity, Innovation and Globalisation: Firm-Level Evidence on the Economic Impact of ICT

The report provides new evidence on these questions using a range of approaches. The majority of the report is rooted in a “micro-to-macro” approach that utilizes a large-scale, cross-country firm-level database on ICT and productivity. This database is used to provide the reports main findings on productivity, ICT adoption, innovation and globalisation. In terms of productivity, section I.A makes the following major findings:

- ICT capital is characterized by high and indeed “above-normal” returns. Evidence from European production functions indicates that a 10% increase in ICT capital is associated with a 0.23% increase in firm productivity whereas theory suggests that this effect should be closer to 0.16%. In turn, this finding suggests that unmeasured, complementary assets may play a big role in determining the overall impact of ICT.

- In terms of cross-country differences, the firm-level data for Europe indicates that there are clear differences in the impact of ICT between the UK and other European countries. Production function estimates that use industry fixed effects indicate that that the ICT co-efficient for UK firms is twice as large as that for firms in other European economies. Approximately one-third of this difference is accounted for by compositional variables (such as more detailed industry controls) and the rest of the difference is due to unobserved firm characteristics. Again, this finding is consistent with the hypothesis that unmeasured complementary factors play a major role in determining the return to ICT.

- Firm-level estimates for Europe also suggest that labour market regulation (LMR) and product market regulation (PMR) may be significant determinants of cross-country differences in the impact of ICT. High levels of labour and product market regulation are associated with a lower productivity impact of ICT. This effect seems to be most severe with respect to labour market regulation (LMR). The LMR effect offsets the main effect of ICT by approximately -45% while product market regulation (PMR) has a more limited offsetting impact of -16.2%.

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[1] See the research by Jorgenson et al (2008) and van Ark et al (2008) for more details on the findings from the growth accounting literature.

The work in Section I.A on productivity also reports on three additional topics: reallocation, ICT investment and spillovers. We summarise these below along with evidence on ICT adoption and diffusion:

- ICT is found to have a significant role in the process of reallocation. Firms with high levels of ICT are more likely to grow (in terms of employment) and less likely to exit. Firms in the top two quintiles of ICT intensity grow around 25-30% faster than other firms and are 4% less likely to exit. Labour and product market regulation are also found to have a role in blunting these forces of selection. That is, low-tech firms in highly regulated economies are more likely to grow and survive than firms in less regulated countries.

- The report models ICT investment at the firm-level and compares its dynamics with physical capital investment. The two types of investment have similar features: both are strongly demand-driven (that is, determined by overall firm sales) but ICT investment adjusts more quickly (by approximately one-third faster) to a given demand shock.

- In principle, firms could benefit from the usage of ICT by other firms in their region or industry. This type of spillover would provide a rationale for policies such as subsidies and tax incentives to encourage ICT investment. However, our test for ICT spillovers in terms of productivity indicates that the evidence for spillovers disappears once we control for the relevant industry and region characteristics.

- However, evidence of spillover effects is found in terms of technology adoption. This implies that ICT usage by “neighboring” firms could induce more ICT adoption through learning, network effects or fostering the growth of skilled labor pools. Unlike direct ICT spillover effects in the production function, these are not so clearly externalities that lead the market to under-supply ICT.

- Other evidence on ICT adoption indicates that: PC adoption is 20% higher in Western Europe compared to Eastern Europe (controlling for all available observables); multinational status is associated with 10% higher PC adoption, and wages are strongly linked to higher technology adoption (with a 10% increase in wages associated with 1% higher PC adoption).

- In terms of policy conclusions, this evidence on productivity and ICT diffusion suggests that extensive subsidies and tax incentives for ICT investment are not warranted by the spillovers that characterize other types of knowledge capital (such as R&D). However, the greater sensitivity of ICT investment to demand does suggest that there is some scope for ICT to play a role in stimulus programmes as it responds more quickly compared to physical capital. Finally, there is systematic evidence at the firm-level that labour and product market regulation affect the productivity impact of ICT and that this can explain cross-country differences.

The “micro-to-macro” firm-level approach is also used to analyse the links between innovation and ICT. While it is clear that ICT has contributed to innovation (particularly in its role as a “general purpose technology”) the nature of this contribution has not been codified. For example, ICT could affect innovation through channels such as: stimulating patenting; assisting product and process innovation; or improving the firm-level stock of intangible capital. The report explores all of these channels along with a detailed analysis of organisational capital at the firm level. Section II makes the following findings:

- ICT is not strongly associated with increased innovation as measured by formal patents. However, ICT is systematically used by firms as part of their strategies for product and process innovation. In particular, our study of the French car dealership industry shows that firm's ICT-based product innovation is favoured over process innovation in situations where competition increases.

- ICT also contributes to the stock of intangible capital at the firm-level. Evidence from firm-level production functions suggests that "own-account" software is strongly associated with firm productivity. Purchased software has a weak relationship with productivity but may be subject co-invention costs, that is, the introduction complementary investments. Finally, network hardware (a specialized form of tangible ICT capital) is also strongly associated with firm productivity. This research represents the first firm-level evidence on the role of intangible ICT capital.

- Decentralisation is seen as an important feature of organisational capital at the firm-level as it closely related to the local flexibility that firms have to implement new production techniques. Our firm-level analysis shows a strong interaction between decentralized structures and the impact of ICT. Even when controlling for firm fixed effects, the interaction between decentralisation is associated with a one-third increase in the impact of ICT investments.

In section III the report also uses the "micro-to-macro" approach to look at issues related to globalisation. The main focus of this research is the operation of multinationals and the role of trade in encouraging technology adoption:

- International firm-level evidence on the structure of multinationals shows that firms are systematically dividing their activities across countries according to technological intensity. Low-tech activities (defined according to our ICT-based technology ladder measure) are 11% more likely to be located in China, the major global site for low wage production. In comparison, high-tech activities (defined following the same measure) are 6% more likely to be located in the home country of the multinational.

- We find that trade is an important driver of innovation in general and ICT adoption in particular. We show that the growth of import competition from China has forced firms to adopt ICT and innovate to avoid the "commoditisation" of low wage country competition. Low ICT intensive firms are much more likely to shrink and die when faced by Chinese competition than higher tech firms. Thus, trade has the benefit of inducing faster technical change both for surviving firms and through a reallocation effect. Practically, our results imply that 15% of the increase in ICT intensity in European manufacturing between 2000-2007 is explained by increase low wage trade competition. Approximately 4% of this total is due to a reallocation effect while the remainder is accounted for by the "within-firm" upgrading of ICT among continuing establishments.

- Multinationals are more intensive users of ICT and US subsidiaries use more ICT than other comparable multinationals while also gaining a higher return to this ICT. In the report we combine the ICT investment data with detailed information on management practices to test the complementarities hypothesis in the context of multinational subsidiaries located in the UK and Europe.

- The evidence on US multinationals operating in Europe suggests that approximately half of the US-EU productivity differential over the 1995-2005 period can be accounted for by organisational capital. Specifically, our empirical work in sections II.D and III.A puts forward direct measures of different types of management practices and finds that they interact significantly with ICT in determining firm-level productivity. US multinationals are characterised by better management practices, particularly in the area of "people management". Note that this part of the gap represents the US-specific advantage in using a *given level* of ICT capital. The remaining half of the gap can be attributed firstly to the advantage that US firms gain from possessing *higher levels* of

ICT (this accounts for approximately 25% of the gap) and secondly to other firm characteristics such as skills (which comprises the remaining 25%).

The evidence on multinationals is particularly important because it links the findings on productivity (specifically the "above-normal" returns of ICT); organisational capital; and product and labour market regulation. These links occur in three logical steps. Firstly, the evidence on management practices confirms the hypothesis that the above-normal returns to ICT are linked to complementary organisational capital. The research in this report confirms this with direct measures of organisational capital. Secondly, the evidence that US firms have better endowments of organisational capital is closely related to the finding that labour and product market regulation affect the return to ICT. Specifically, the mechanism behind this link is that lower levels of LMR and PMR have an active role in *lowering the costs of developing organisational capital*. Thirdly, the final link is that, having developed this organisational capital, US firms can then export it to their subsidiaries in other countries. Hence we find in our European data that US firms are more productive with higher levels of organisational capital even in environments characterised by strict labour and product market regulation.

Our finding of extensive complementarities between ICT and organisational capital has a number of important policy implications. The key to making more effective use of ICT in Europe is to *remove barriers to the accumulation of these complementary factors*, in particular, people management and decentralisation. This can be achieved through support for policies that promote product market competition, faster adjustment in the labour market and openness to trade. The report finds strong support for these types of policies based on new evidence at the microeconomic, firm-level. Furthermore, the report is unable to find support for the alternative line for ICT investment policy founded in technology spillovers and interventionist policies to correct market failures.

Studies of Prices, Spatial Concentration and Work-Life Balance

The report also uses alternative methodologies (not necessarily based on firm-level data) to produce findings on other topics. These findings include:

- ICT investments in Europe and the US have been associated with major falls in producer prices – the "factory gate" prices that underpin retail prices. These falls have taken place not only in the ICT-producing sectors but also across other manufacturing industries. ICT investment is associated with around a 0.3% per year fall in European producer prices. As a comparison, low-wage import penetration (specifically Chinese imports) is associated with a 0.3% fall in producer prices. Therefore the contribution of ICT to falls in producer prices ranges from 50-100% in magnitude compared to import penetration.

- An analysis of ICT and spatial concentration patterns for the UK indicates a negative relationship for manufacturing and a positive relationship for services. That is, higher levels of ICT are associated with less spatial concentration for manufacturing and vice versa for services. While the result for manufacturing is robust to the inclusion of industry controls the relationship disappears for services.

- The report studies the relationship between ICT and worker job satifaction, particularly work-life balance (WLB). The use of company ICT for private purposes during working hours is positively correlated with perceived WLB. However, the use of company ICT after hours is *negatively* associated with ICT. This latter finding is also associated with higher working hours indicating that job attributes may driving the relationship between ICT usage and WLB. We also find that family-friendly work practices have a strong relationship with firm performance (measured in terms of profitability). Furthermore, flexibility enhancing ICT only has effects on performance when it is combined with family-friendly work practices.

Conclusion and Future Scenarios

The major theme of the report is the development of a clear rationale for ICT-focused economic policies. The report concludes that ICT investment policies should be guided by a different logic to other areas of innovation policy. Rather than being focused on correcting market failures in ICT investment, policies in this area need to focus on assisting the accumulation of a number of complementary factors, principally organisational capital and skills. While subsidies and tax incentives are vital in other areas of innovation policy (such as R&D expenditure) they are not suited to attacking the root causes of Europe's failure to exploit the economic benefits of ICT. Using new microeconomic evidence, this report systematically shows that the priorities for ICT-focused economic policies should be placed within the overall policy agenda for promoting labour and product market reform, including reforms with respect to trade openness and the effective operation of the education system.

Future scenarios for the economic impact of ICT hinge on two determinants. The first is the development of the ICT-production sector, specifically the rate of price change for ICT equipment. The rapid falls in ICT equipment prices post-1995 were responsible for stimulating productivity growth in the ICT intensive industries and further sharp falls would have similar effects. However, it is difficult to predict the path of ICT prices due to the range of technological trends underway in the production and use of ICT. The second determinant is the presence of complementary factors such as skills and organisational capital. Falls in ICT prices can only go some of the way in stimulating growth: they need to be combined with adequate complementary factors for the full benefits of ICT to be realised.

The interaction of these two factors is at the heart of future scenarios for US and EU productivity growth. If the rate of ICT price falls was to slow then a process of catch-up may re-emerge whereby slower organisational adjustment in the EU delivers the benefits that should have accrued in the late 1990s. However, if ICT prices fall sharply once again there will be a further divergence in US and EU productivity levels. The role of policy then is to rapidly improve the stock of complementary factors in the EU so it can fully exploit past and future improvements in ICT.

EXECUTIVE SUMMARY AND POLICY IMPLICATIONS

Background

1. The background to the report is that since the mid 1990s, the US economy enjoyed a "productivity miracle". The rate of labour productivity growth (GDP per hour) accelerated remarkably after having been low since the oil shocks of the 1970s. Specifically, US productivity growth accelerated from an average rate of 2.08% in the 1973-1995 period to a rate of 4.77% in 1995-2000. ICT played a major role in this acceleration in terms of capital deepening (ie: increased investment in ICT capital) and total factor productivity (TFP) growth. TFP growth in the ICT production sector increased from 0.25% to 0.58% when comparing 1973-1995 and 1995-2000. Similarly, the rate of ICT capital deepening more than doubled from 0.40% to 1.01% between these two periods (Jorgenson et al 2008). Although US productivity growth initially appeared to be returning to "normal" levels in the 2005-2007 period, the last 2 years of global turmoil appear to have coincided with faster productivity growth again. So, at the time of writing, it is far from clear that the productivity miracle is over.

2. By contrast, the EU did not enjoy the same productivity acceleration after 1995 and the convergence of EU-US productivity levels that had been happening for 50 years swung into reverse. While there was only a 1.8% gap in the level of output per hour worked between the US and the EU in 1995 this increased to a 9.7% gap by 2004. Since productivity is the key measure of economic wellbeing in the long run, this is a source for concern for European policy-makers. The US-EU gap increased most in the ICT production sector (where US labour productivity growth was almost double that of the EU over 1995-2004) and the market services sector (where US growth was more than three times greater than the EU) (Van Ark et al 2008).

3. The increased importance of ICT in driving US productivity growth overturned Robert Solow's paradox "that computers were found everywhere except the productivity statistics". But since ICT is available in Europe at roughly similar prices, a major puzzle is why the EU has not also shared equally in the benefits of this ICT based revolution.

4. A further puzzle was uncovered in research using firm-level data on productivity and ICT. Estimates of the impact of ICT on productivity suggested that high and "above-normal" returns accrued to investments in ICT. This finding led to a further hypothesis that ICT was proxying for the contribution of complementary investments, particularly organisational capital. However, data limitations prevented the detailed investigation of this hypothesis.

5. The growing economic importance of ICT also raised new policy questions. In particular, previous approaches to innovation policy were based on the principle that spillovers from knowledge capital (such as R&D) justified public intervention in the form of subsidies and tax incentives. It has been unclear whether ICT investment merits the same policy framework or is better served by alternative policies. Furthermore, while it is clear that ICT has contributed to innovation (particularly in its role as a "general purpose technology") the nature of this contribution has not been codified. For example, ICT could affect innovation through channels such as: stimulating patenting; assisting product and process innovation; or improving the firm-level stock of intangible capital.

6. The rapid diffusion of ICT in the 1990s has raised many other economic policy questions. In terms of spatial activity, various theoretical and empirical contributions

have suggested that ICT's impact on the distribution of activity was ambiguous. Furthermore, while falls in ICT producer prices have been a central part of the literature on the productivity miracle the role of ICT on prices in other sectors has not been explored.

Methodology

7. To address the puzzles raised by the existing evidence on ICT and productivity, we proposed a "micro-to-macro" approach that is rooted in microeconomic decision-making at the firm-level. It is based on the view that in order to understand economic aggregates, such as productivity, we must understand what is happening at the firm-level and how companies respond to changes in the economic and policy environment. Looking at country-wide and industry-wide data is inadequate; to tackle the complexities we must use, gather and analyse data at the level where decisions are actually made, the firm level.

8. A key component of the methodology is the compilation and analysis of large-scale and original company databases on hundreds of thousands of observations. Typically these follow the same companies over a number of years across many countries in Europe and overseas and allow us to implement sophisticated econometric models of firm-level behaviour.

9. Although we utilise many databases, the major one we have put together is AMATECH. This combines company-level accounting data from: (i) BVD's Amadeus – containing productivity, investment, employment and wage data covering close to the population of firms in all European counties; (ii) Harte Hanks' data on ICT - covering hardware, software and ICT personnel data on most EU nations and the US, (iii) the European Patent Office data on all European patents and their citations since 1978. We combine this with many other sources of industry and macro data, but also with the CEP's own surveys into the managerial and organisational structure of firms (covering about 7,000 interviews with plant managers across 17 countries).

10. Our data collection effort is complementary with other Commission funded datasets on ICT. First, EU-KLEMs can be matched to our data. KLEMS has the advantage of covering more years, but the disadvantage of quite aggregated industry-level (rather than firm-level) data. Second, Eurostat/ONS have finished a project on 13 countries using National Statistical Office data on establishments. This has the advantage of being matched to confidential statistical office data, but the disadvantage that it is not publicly available and that only two countries have "stock" data on ICT. Nevertheless, most of our findings are consistent with the results on these complementary databases.

Empirical Findings – Firm-Level Evidence on Productivity, Innovation and Globalisation

Productivity

11. We find in section I.A that there is considerable evidence of a large impact of ICT on firm productivity among both US and European firms. This impact is beyond that which would be expected given the share of ICT in expenditure. Second, the impact of ICT on productivity varies hugely between different firms: some firms can spend large amounts and see very little return whilst others receive a bonanza of enormous returns. Therefore as one of the major empirical themes of the report, we seek to explain this variation in returns and, in particular, draw out the implications of this finding of "above-normal returns" to ICT capital.

12. As an example, our preferred estimate of the impact of ICT on firm productivity in Europe indicates that a 10% increase in ICT investment leads to a 0.23% increase in productivity whereas theory suggest that this effect should be closer to 0.16%. This estimate is consistent with similar estimates for the US and suggests that ICT may be picking up the influence of omitted factors. Our report therefore explores how this return to ICT varies with industry and firm-level characteristics, particularly skills and organisational structure.

13. The productivity of ICT is much larger for the "ICT using" sectors such as retail and wholesale. This is interesting as the data is not contaminated by being closely connected with the finance-led bubble. Furthermore, these industries account for a large proportion of the US productivity miracle and are not seen as traditionally high-tech sectors. This is also an area where there have been many complementary innovations. By contrast, we found no systematic difference by firm size, age or region.

14. In terms of cross-country differences, the firm-level data for Europe indicates clear differences in the impact of ICT between the UK and other countries. In baseline specifications with 2-digit industry controls the ICT coefficient is approximately 0.24 for the UK and around 0.10-0.15 for countries such as Germany, France, Italy, Spain, Austria, Sweden and Denmark. Approximately one-third of this difference is accounted for by compositional variables (such as 4-digit industry controls) while the rest is largely eliminated once unobservable firm-level factors have been accounted for. This indicates that in the context of firm-level data, cross-country differences seem to be determined mainly by the distribution of unobservable characteristics. However, even with industry fixed effects the UK ICT coefficient is approximately 0.015 while the coefficient for most other European countries is insignificantly different from zero.

15. Furthermore, country-level differences in labour and product market regulation are associated with significant differences in the impact of ICT across countries. High levels of labour and product market regulation are associated with a lower productivity impact of ICT. This effect seems to be most severe with respect to labour market regulation (LMR). The LMR effect offsets the main effect of ICT by approximately -45% while product market regulation (PMR) has a more limited offsetting impact of -16.2%. Finally, the magnitude of these offsetting effects is consistent with the extent of the cross-country differences in ICT and productivity, suggesting that regulation could play a leading role in explaining cross-country differences (Gust and Marquez 2004 suggested this solely using macroeconomic data)..

16. The evidence on US multinationals operating in Europe suggests that approximately half of the US-EU productivity differential over the 1995-2005 period can be accounted for by organisational capital. Specifically, our empirical work in sections II.D and III.A puts forward direct measures of different types of management practices and finds that they interact significantly with ICT in determining firm-level productivity. US multinationals are characterised by better management practices, particularly in the area of "people management". Note that this part of the gap represents the *US-specific advantage* in using a given level of ICT capital. The remaining half of the gap can be attributed firstly to the advantage that US firms gain from possessing *higher levels* of ICT (this accounts for approximately 25% of the gap) and secondly to other firm characteristics such as skills.

17. As emphasized above a major innovation of the report is that we are able to directly measure important dimensions of firm-level organisational and human capital. Analyses of this depth were not feasible under previous industry-level and macroeconomic growth accounting frameworks. In particular, we find that the management and organisational practices of the firms such as *people management* (better hiring, firing, promotion and pay practices) and *decentralisation* (giving more power to employees

further down the managerial hierarchy) appear complementary with ICT. Additionally, skills appear to be very complementary with ICT.

18. We find a significant role for ICT in influencing productivity through reallocation, that is, the ongoing process of selection and relative firm growth in the economy. This represents the first major test of ICT's role in reallocation using international firm-level data. More ICT intensive firms appear to grow faster and are less likely to die than other types of firms. That is, "high-tech" firms rich in ICT capital are more likely to grow and survive than other types of firms, even after controlling for other important characteristics such as wages (a proxy for skill) and initial productivity. For example, the top two quintiles of high-tech firms are found to grow around 25-30% faster in terms of employment and are also 3% more likely survive over a 5-year period. This implies that the environment is favouring such firms and that they contribute to overall productivity growth through this reallocation effect. In terms of cross-country variation for Europe, we find that technological selection effects are strongest for the UK and weakest for Austria, Finland and Switzerland.

19. In line with the production function results we also find that labour and product market regulation have a significant role in blunting technologically-based selection effects in reallocation. Analysing employment growth, we find that LMR reduces the ICT selection effect by one-third while PMR reduces it for approximately one-fifth. Again, the magnitude of these LMR and PMR effects suggests that these institutions could be a systematic driver of cross-country differences in reallocation and, therefore, productivity.

ICT Spillovers

20. In principle firms could benefit from ICT "spillovers" in the sense that ICT investments by other firms in the industry, region or further afield could improve the productivity of firms, over and above the ICT investment that a firm is making. For example, firms may learn from other local firms about the best way to use new technologies. These spillovers could affect firms in terms of two outcomes, firstly, the adoption of technologies and, secondly, through the higher productivity as a result of these investments.

21. We find that there is only weak evidence in favour of such ICT spillovers in terms of productivity (section I.A). Increases in ICT by other firms in the same region or industry do not seem to cause significant increases in a firm's own productivity. In the cross section, a firm in a region (or industry) where many other firms have high ICT has higher productivity. But this disappears when we control for regional dummies, suggesting that this correlation is not due to spillovers but rather because regions (and industries) are different on other dimensions – e.g. more skills, better demand conditions or more technological opportunities.

22. However, evidence of spillover effects is found in terms of technology adoption (section I.B). A way to reconcile this is that ICT usage by "neighboring" firms could induce more ICT adoption through learning, network effects or fostering the growth of skilled labor pools. However, these mechanisms (which induce a kind of strategic complementarity between firms' ICT decisions), do not increase productivity unless a firm adopts more ICT. Unlike direct ICT spillover effects in the production function, these are not so clearly externalities that lead the market to under-supply ICT.

Investment and Adoption of ICT

23. Investment in ICT is driven by many factors. The report outlines the first investment equation for ICT capital in the literature and contrasts its dynamics with those of

physical capital. We show that demand, as measured by the growth in firms sales, is an important determinant of both ICT and physical capital investment. We also find that investment responds more quickly to demand shocks than other forms of physical capital investment (e.g. in buildings and machinery).

24. ICT adoption is modeled following three approaches: macroeconomic diffusion, microeconomic adoption and microeconomic timing. On macroeconomic diffusion we find that patterns related to PC adoption do not follow the traditional *S*-shape found for many other technologies. This may be because PC adoption involves an important "intensive" margin, that is changes in the intensity of application at the firm-level are important for this type of generic technology.

25. Microeconomic models of PC adoption show that high wages and firm size are important determinants of technological intensity. A 10% increase in wages is associated with a 1% increase in technological intensity. However, by comparison multinational status is associated with a 10% premium in terms of PC intensity. When looking at overall cross-country differences we find that there are minimal differences in PC intensity after controlling for all available observables. Western European firms have on average 2 more computers per 10 employees than Eastern European firms, but cross-country differences within Western Europe are very limited.

26. In terms of equipment adoption we look at specific types of software applications such as ERP (Enterprise Resource Planning software like g. HRM and CRM) and databases. Larger firms are more likely to adopt earlier. Firms adopting ICT are more likely to do so if other firms also adopted a lot of ICT in the previous year. This could be consistent with ICT spillovers, but seems to be due to other factors such as better expected demand conditions or other industry-wide improvements in the environment.

Innovation

27. We examine whether ICT has facilitated more innovation as measured by patents. After controlling for unobserved differences by including fixed effects, it does not appear that there is a significant effect of ICT on stimulating more innovationas represented by patents. However, this measure of innovation (patents) is a narrow one and does not capture the full range of product and process innovations where ICT has a major role. ICT also contributes to the stock of "intangible" capital that underpins innovation activities at the firm-level.

28. Using a new approach, we identify different types of tangible and intangible ICT capital, and examine in their relationship with productivity in a microeconomic production function framework. We find that the "own-account software" component of intangible ICT capital is strongly associated with firm productivity. In addition, network hardware (here categorised as another type of tangible ICT capital) is also strongly associated with productivity. Finally, the "purchased software" component of ICT capital appears to have a limited relationship with firm productivity. This may be due to the "co-invention costs" of deploying new software systems and again emphasizes the need for complementary assets in making ICT investments fully effective.

29. In a study of the French car dealer industry, we look more closely at the role of ICT as a vehicle for product and process innovation. Specifically, we look at the effects of a change in product market regulation on technological adoption in the industry. This change in product market regulation increased competitive pressure in the industry and subsequently increase scale in the industry. That is, firms expanded in size as new markets opened up due to deregulation. In terms of innovation, this increase in scale was associated with the increased adoption of product innovations by firms, but less process innovations. Practically, this suggests two things, firstly, that product innovation

is preferred when firm scale is a consideration and secondly that product and process innovation are seen as substitutes by firms. This latter finding may be the result of managerial or financial constraints on the simultaneous adoption of the two types of innovation.

Organisational Design

30. Within-firm decentralisation is frequently considered an important aspect of organisational design, giving firms the local flexibility to implement productivity-enhancing processes, tasks and procedures. Our firm-level analysis shows a strong interaction between decentralized structures and the impact of ICT. Even when controlling for fixed effects, the interaction between decentralisation is associated with a one-third increase in the impact of ICT investments.

31. Different types of ICT also have distinctive effects on the organisational structure of firms. Enterprise Resource Planning (ERP) systems have an important role in facilitating information acquisition and are strongly liked to higher levels of *plant manager autonomy*. Network technologies in contrast are associated with less plant manager autonomy since they lower the costs of head office monitoring and intervention. Finally, Computer Aided Design (CAD/AM) tools are linked to higher levels of *worker autonomy* as they assist workers in acquiring information on local production tasks.

Globalisation

32. The report provides new information on how multinational firms divide their activities across countries. We examine the subsidiary and detailed industry information for the Top 100 multinationals active in Europe who collectively own 21,000 subsidiaries around the world. We classify these subsidiaries according to the technological intensity of their industry activities. This allows us to define a “technology ladder” of low and high tech industries.

33. The evidence on the location of these industries supports the idea that multinationals are locating their low-tech activities in low-wage countries. Specifically, we find that a multinational subsidiary located in China (the major global site for low wage production) is 11% more likely to be classified as “low-tech” according to our technology ladder indicator. This effect is evident even when control for the global ultimate owner meaning that this is strong “within-firm” phenomenon. There is also evidence that the major multinationals are 6% more likely to keep high-tech activities in their home country. However, this finding is not as strong in terms of within-firm effects.

34. Multinational firms appear to use ICT much more than domestic firms. Interestingly the subsidiaries of US multinational firms in Europe appear to use more ICT and obtain higher productivity from their ICT than subsidiaries of other multinationals in Europe. This is consistent with the aggregate productivity miracle data suggesting that the US is more effective at using ICT. Analysing this further using the CEP management and organisation surveys, we find that the US ICT advantage is due to people management practices – US firms appear to make better use of incentives in their promotion, pay and personnel decisions, which appears complementary to ICT.

35. The example of US firms in Europe allows us to calibrate some of the observed differences in US-EU labour productivity. Firstly, production function results for the UK sample indicate that US firms experienced 0.8% per year faster labour productivity growth in the 1995-2004. When weighted by the proportion of ICT using firms this then accounts for half of the US-EU labour productivity growth differential. A similar productivity of US MNE status is observed in our European panel.

36. The differential can be unpacked further when considered in conjunction with detailed management practices data. This shows that half of the US productivity advantage is explained by higher levels of effective people management practices. Hence, this supports the idea that a large fraction of the US-EU labour productivity differential can be explained in terms of organisational capital. This is the first decomposition of US-EU productivity differences that is explicitly based on measured differences in organisational capital.

37. We find that trade is an important driver of innovation in general and ICT adoption in particular. We show that the growth of import competition from China has forced firms to adopt ICT and innovate to avoid the "commoditisation" of low wage country competition. Low ICT intensive firms are much more likely to shrink and die when faced by Chinese competition than higher tech firms. Thus, trade has the benefit of inducing faster technical change both for surviving firms and through a reallocation effect. Overall, increased lo wage country trade can account for 15% of the increase in ICT intensity for European manufacturing (from 2000-2007), with 11% due to within-firm upgrading and the remainder a result of reallocation.

38. Another aspect of globalisation is whether distance matters less. We find that for university based inventions, distance does matter – patent citations are much less likely the further firms are from the university that made the breakthrough. Local policies have an effect on this – a university which is mandated to have more of a local focus, does not see its ideas spread out so quickly. This effect of distance has declined in recent years (distance is dying, but it is not dead), consistent with the idea of lower communication costs. Further, distance is much less important for ICT innovations, suggesting that these do spread much more quickly.

39. As basic economic theory would predict, we found that the largest multinational firms were founding their Chinese subsidiaries in low ICT-intensive industries, presumably to use cheaper labour. By contrast their subsidiaries in developed countries were in more ICT-intensive sectors.

Empirical Findings – Studies of Prices, Spatial Concentration and Work-Life Balance

Regional Inequality

40. Policy makers have been concerned with whether ICT could lead to greater disparities across regions in the EU. The effects on spatial concentration are theoretically ambiguous. Geographic concentration of economic activity ("agglomeration") could rise if ICT makes clustering stronger (e.g. one "Silicon Valley" instead of many smaller clusters). But ICT could decrease spatial inequality if lower communication costs mean that workers can locate even in geographically isolated areas.

41. Our analysis of the "digital divide" in technological adoption indicates the inclusion of regional characteristics, and industry controls explains around 50-70% of differences at the NUTS1 level for Germany, the UK and France. Again, like the cross-country results, this suggests that inter-regional differences are limited after controlling for observable characteristics. This finding is important because it sets a bound on how much policy-makers can influence technological adoption given existing patterns of industrial composition.

42. An analysis of ICT and spatial concentration patterns for the UK indicates a negative relationship for manufacturing and a positive relationship for services. That is, higher levels of ICT are associated with less spatial concentration for manufacturing and vice

versa for services. While the result for manufacturing is robust to the inclusion of industry controls the relationship disappears for services.

ICT and Prices

43. ICT investments in Europe and the US have been associated with major falls in producer prices – the “factory gate” prices that underpin retail prices. These falls have taken place not only in the ICT-producing sectors but also across other manufacturing industries. ICT investment is associated with around a 0.3% per year fall in European producer prices. As a comparison, low-wage import penetration (specifically Chinese imports) is associated with a 0.3% fall in producer prices. Therefore the contribution of ICT to falls in producer prices ranges from 50-100% in magnitude compared to import penetration. The most likely mechanism for this ICT-led fall in prices relates to productivity growth. That is, by increasing productivity ICT has expanded “potential output” and relieved supply-side pressures on producer price inflation.

44. Popular debate regarding the impact of ICT on consumer prices has focused on the availability of cheaper electronic goods and the rise of online retailing and delivery. We find evidence of significant falls in prices for Recorded Media and Electronic Goods and Equipment. These falls have been of the order of -3.5% per year for Recorded Media and -9% per year for Electronic Goods and Equipment. In contrast, the prices of books and newspapers have either moved neutrally with overall prices or increased slightly. However, the markets for books and newspapers could be affected by quality and compositional changes as publishers adjust their formats in response to online competition. Overall, cross country variation in these product price changes is minimal and in this case does not seem to be related to any trends in broadband penetration or labour and product market regulation. Furthermore, it must be noted that given the evidence on producer prices we uncover, it seems that ICT is having an effect on prices outside of the obvious consumer price categories we consider here.

45. The evidence on household expenditure indicates that ICT-related goods only represented a small fraction of total expenditure – approximately 5% with minimal variation across countries. Hence, the direct impact of potential ICT-induced price falls is limited, even when considering possible substitution and income effects. However, the findings on producer prices indicate that their price impacts outside of narrowly defined ICT-related goods may also feed into household expenditure.

Work-Life Balance and Job Satisfaction

46. The links between ICT and Work-Life Balance (WLB) depend on how and when ICT used. The use of company ICT for private purposes during working hours is positively correlated with perceived WLB. However, the use of company ICT after hours is *negatively* associated with ICT. This latter finding is also associated with higher working hours indicating that job attributes may driving the relationship between ICT usage and WLB. However, we also find that there is a positive relationship between WLB and the after-hours use of company ICT when this ICT is used in conjunction with flexible work practices.

47. We also study the relationship between firm performance and the incidence of both family-friendly work practices (FFWP) and flexibility-enhancing ICT (FLEX_ICT). Family friendly work practices are fond to have a strong positive relationship with profitability measures such as the return on assets (ROA) and the return on sales (ROS). In contrast, flexibility-enhancing ICT only shows a strong relationship with firm performance when it is combined with the presence family-friendly work practices.

Overall, these results indicate that there may be strong complementarities between ICT usage and firm organisational practices when considering WLB.

Policy Implications

Policies to Relieve Barriers to ICT investment: Competition and Human Capital

48. Our finding of extensive complementarities between ICT and organisation/management has a number of important policy implications. The key idea is, to make more effective use of ICT in Europe is to *remove barriers to the accumulation of these complementary factors*, in particular, people management and decentralisation. One of the most important drivers of better people management is stronger product market competition as competition tends to drive out the poorly managed firms and incentivises surviving firms to upgrade their management skills (e.g. Bloom and Van Reenen, 2007). Furthermore, we show that competition also tends to foster decentralisation as firms need to make decisions more quickly when competition is fierce. Whatever the other benefits from competition (e.g. lower prices and greater product variety) it will also benefit ICT adoption through stimulating decentralisation and better people management. Reforms to widen the single market, particularly through the stalled Services Directive, are extremely important in this regard. The Services Directive is particularly important in that , firstly, it represents a major new set of product market reforms that could enhance competitive pressure and, secondly, because there is evidence that ICT has a higher productivity impact in a number of "ICT-using" service industries. The directive is therefore an important policy mechanism for encouraging ICT adoption and enhancing productivity. Competition policy in general also needs to be robust and consistent. Finally, trade is also a lever of increased competition (discussed below).

49. Another factor hampering better people management is tough labour market regulations, which impede firm's abilities to hire, fire, pay and promote in a way that maximises their productivity. Europe has much stronger labour market regulations than the US and we believe this is why its people management practices are weaker than those of American firms. This hampers the ability of European firms to rapidly adopt their organisational structures to most effectively use new ICT technologies. As such, another policy implication is to promote less restrictive labour markets in Europe.

50. Another important complementary investment is human capital. Policies to deepen human capital through reforms to universities, improvements in schooling, better business education and training can have a "triple win". First, human capital will increase productivity in its own right independently of ICT. Second, more skills will speed up the diffusion of ICT as we have discussed. Third, increased human capital will reduce inequality pressure. The falls of the price of ICT increase demand for the most skilled workers contributing to an increase in their wages and therefore inequality. Pro-ICT policies (like tax subsidies) in the absence of a greater supply of skills will tend to increase inequality across individuals (even if they do not increase inequality between regions).

Spillovers and Direct ICT Subsidies

51. We do not find evidence for large ICT spillovers. After controlling for unobserved heterogeneity there is no effect of a "neighbour's" ICT (e.g. in the same region or industry) on a firm's own productivity. Nor is there evidence that ICT itself stimulates more (spillover creating) innovation directly.

52. Our results, which found little evidence for ICT spillovers, is consistent with results from US data, and contrasts to the strong evidence that spillovers are large for R&D and

human capital. For these other intangible investments, knowledge has externalities (it is "non-rival and only partly excludable") that means there will be too little incentive to invest from the private sector. But for ICT it is much less clear even in theory what these externalities are. *Thus, the evidence base here implies there is no strong basis for general direct subsidies to ICT in the form of subsidies or tax breaks.*

Stimulus Programmes

53. The greater sensitivity of ICT investment to demand does suggest that if there are stimulus programs for investment in response to downturns (such as the current global recession), ICT investments will respond more quickly than other forms of capital (such as structures or equipment). At the time of writing, the recession appears to be ending, however, so the value of further demand stimulus programs is unclear.

Regional Policy

54. Since we find that ICT appears to reduce industrial concentration by region there is no sense in which ICT is likely to increase regional disparities – it is more likely that ICT is a force for *spatial* equality (even though it might increase inequality across countries).

Trade Policy

55. Openness to trade is a powerful positive force for stimulating ICT. We find that in the 2000-2007 period, greater trade with China accounted for 15% of the ICT upgrading in Europe. In addition, there are positive competitive effects on organisational forms complementary to ICT (e.g. trade competition stimulates decentralisation with fosters ICT). Thus, together with the standard positive benefits of lower prices from further trade liberalisation there is an under-appreciated positive trade effect on innovation and technological adoption. Consequently, re-invigorating the Doha Round and unilateral removal of European trade barriers would be desirable on ICT grounds.

Foreign Direct Investment

56. Removing barriers to foreign ownership would help spread ICT, especially reducing barriers against US ownership. Multinationals are one of the key routes through which management practices and know-how on how to best use ICT are spread internationally. The crisis has meant much more government involvement in the economy. Although this was necessary in the short-term, we must guard against this being a way of returning to "national champions".

Universities

57. Universities are a major source of innovation and not only in the ICT sector. From a pan European perspective, restrictions on the ways universities operate reduce the speed at which their innovations spread across Europe and benefit firms further away from where the university is located. Allowing greater autonomy for universities, incentivising academics to upgrade research quality and allowing improved university finance through charging students fees that reflect true costs, would all be welcome policy changes.

Future Scenarios

58. Future scenarios for the evolution of ICT and productivity are best evaluated in the growth accounting framework. The critical element in these projections is the future rate of TFP growth in the ICT–producing sector. In particular, improvements in semi-conducter production contributed to large falls in quality-adjusted ICT prices and

underpinned the post-1995 productivity miracle. In both the baseline and “pessimistic” scenarios the fall in ICT prices is at best a one-off occurrence and labour productivity growth reverts to an average rate of 1.4-2.4% in the 2010-2020 period. One interesting implication of these scenarios is that European productivity growth should “catch-up” to US levels due to the effects of slower organisational change combined with ICT investment.

59. However, an “optimistic” scenario characterized by sharply falling ICT prices (approximately 30% per annum) cannot be ruled out. Under this scenario high productivity growth continues and a permanent productivity gap develops between the US and EU. The reason this scenario cannot be discounted is the uncertainty over the future development of ICT. Improvements in semi-conducters may be accompanied by other major ICT breakthroughs, particularly in terms of network based applications. Emerging technological trends such as infrastructure convergence, human-computer convergence and utility convergence are extending the economic domain of ICT applications. In particular, it is likely that these technological trends will positively affect the intensive and extensive margins of ICT usage in both sectors that already use ICT intensively and potentially new industries.

Research Innovations

60. The report provides a number of innovations that substantially add to the existing findings of international studies based on growth accounting methods. In particular, the firm-level focus taken in the report allows us to quantify the role of previously unobserved factors. In particular, the report clearly identifies the role of firm-level organisational capital (in the form of management practices and the use decentralization) as a major force determining EU-US productivity differentials. This finding is a major addition to the explanations provided in growth accounting studies which have focused most heavily on the contribution of the ICT intensive sectors (both using and producing) as the main drivers of productivity differences.

61. Furthermore, the firm-level focus opens up some completely new topics for the analysis of ICT and productivity. Firstly, the report quantifies the role of ICT as a force influencing productivity growth through reallocation. We identify a unique role for ICT in supporting firm growth and survival over and above the influence of wages, skills or capital. Secondly, we explicitly model ICT *investment* and find it has significant dynamics to physical capital investment. In turn, we also test for spillovers arising from the accumulation of ICT. We are unable to find evidence supporting ICT spillovers for productivity suggesting that ICT subsidies are not warranted in the same fashion as R&D. This provides a new insight into policy design that was not testable in previous growth accounting studies of ICT and productivity. It also represents a major departure from thinking of ICT-related policy as a lateral extension of knowledge economy policies built around the precedent of market failures and R&D.

62. Outside of this firm-level focus the report makes new findings in a number of areas. In an analysis of EU and US producer prices we find that ICT is associated with falls in producer prices outside of the ICT-producing sector. Our analysis of spatial concentration patterns indicates that there is a ICT is negatively related to concentration for manufacturing. In services, there are indications of a positive relationship but this finding is not as robust as the result for manufacturing. Also in terms of spatial issues we find that localised knowledge spillovers are weaker for ICT-related technologies.

Areas for Future Research

63. The major technical or methodological area for future research lies in the estimation of a "causal impact" of ICT adoption on economic outcomes. Natural experiments, that is, events that reproduce the conditions for a quasi-random test of causality are the best candidates for this type of research. Furthermore, it is most likely that credible random experiments could be found in the context of policy changes mapped across different types of industry, region or (ideally) firm-level variation.

64. As part of this emphasis on causality there is a need to build formal policy evaluation frameworks into new policies, particularly those associated with firm or area-specific grants, tax incentives or subsidies. In practice, this requires the collection of good administrative data on policies that can be mapped to economic data such as firm accounts. A similar strategy should be pursued for the evaluation of public sector ICT initiatives. In this case, data on service outcomes could be collected directly from administrative sources.

65. Alongside causality there is need to consider the role of both dissagregated types of ICT and different forms of organisational capital. In this report we have put forward some basic measures of intangible ICT capital but there is scope to create more detailed measures using equipment-specific price information. This should be pursued in conjunction with other efforts to measure the value of intangible capital in national accounts. There is also a need to integrate standardized questions on organisational structures and management practices into the firm-level surveys conducted by national statistical institutes.

66. Finally, there some gaps in the available European data for investigating ICT and productivity issues. In particular, there is a need to consolidate existing Eurostat 4-digit industry-level data on productivity, capital and labour inputs into a single database. While the EU_KLEMS project has constructed such a database at the 2-digit level a consolidation of whatever 4-digit information exists would greatly complement other research. Secondly, the depth of the available European Labour Force Survey micro-data needs to be improved as this would assist research on skills and technical change. Thirdly, the EU's LABREF and MICREF databases on labour and product market reforms have much potential for policy research if a mapping of specific reforms to industries and regions could be devised. Finally, ongoing efforts at comparing firm-level micro-data across countries (for example, recent projects by the OECD) should be supported and expanded.

Summary

67. In summary, we present what we believe is the most comprehensive and rigorous report on the economic effects of ICT. This should inform the evidence base for European policy marking, which we believe should focus on freer product and capital markets, less restrictive labor markets and a continued focus on promoting education.

INTRODUCTION

The Commission asked us to prepare a report on the "Economic Impact of ICT". This is the third and final report that brings together our findings. The first report surveyed the existing literature and the second report laid out our methodology. This report summarises some relevant material from the earlier report but focuses on the findings from the implementation of the methodology outlines in our proposal and detailed in the last report.

The current report is divided into three parts following the Commission's project specification. Part I looks at Competitiveness and Growth, Part II at Knowledge Intensive sectors and Part III at Globalisation. The topics obviously overlap. In this Introduction we do not attempt to summarise the entire document (see the Executive Summary and Policy Conclusions above). Rather, we set the report in recent historical context and summarise the methods and main data that we will use in the rest of the Report.

Historical and Policy Context

The contribution of the knowledge economy to economic growth has been a central topic of policy debate and economic analysis since the late 1980s. The knowledge economy can be defined most generally as those economic activities that involve either the use or production of knowledge or information-based goods and services. The role of ICT has been central to this discussion of the knowledge economy. In particular, the rise of the internet led to the development of many secondary innovations that were dominated by knowledge-based goods and services.

Interest in this topic accelerated with the emergence of an ICT-led productivity resurgence in the US since the mid 1990s, with productivity growth rising to levels not seen since the 1970s oil shocks.[2] The broad consensus was this acceleration was linked closely to the use of ICT, although the production of ICT also played a role. The rapid falls in quality adjusted ICT prices and the diffusion of innovations such as the Internet were major factors.

Europe did not experience the productivity rebound of the US and since 1995 productivity levels have diverged between the two regional blocs. This ended five decades of convergence and has justifiably been a major source of concern for EU policy-makers. Although US productivity growth slowed in 2005-2007, it has sped up again in the 2007-2009 period, so the jury is still out on whether the decade long productivity acceleration is over.

Research Methodology

This report develops a comprehensive and detailed methodology for analysing the economic impact of ICT. The methodology that we develop is designed to make a number of substantial new contributions to the existing literature on the topic. Practically, our approach is comprised of two parts. Firstly, we answer most of the main research questions using a large cross-country sample of firm-level data which contains information on company accounts, ICT equipment, software, patents, R&D, organisational structure and management practices. This firm-level approach is deployed in sections I-A, I-B; I-D of the first topic (Competitiveness and Growth) and forms the bulk of the analysis of knowledge intensive activities and globalisation reported in sections II and II. In the remaining sections we use specialised datasets and research designs to explore specific issues in-depth. The main two examples of this are, firstly, the study of ICT and spatial concentration using the UK ARD (Annual Respondents Database)

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[2] Jorgensen et al (2008) provides a detailed growth accounting analysis of the US while Van Ark et al (2008) discuss differences in performance between the EU and US.

in section I.C and, secondly, the study of spatial knowledge diffusion patterns and US universities again in section I.C.

The first approach based on firm-level data can be summarised as a “micro-to-macro” strategy. The main advantage of our approach is that it integrates diverse topics such as productivity estimation, technology adoption and the modeling of innovation in a single micro-econometric framework. It is consistent with the approach developed in recent leading contributions by Bartelsman et al (2002, 2004) and offers many new insights for policy development.

We outline below this methodology which is based on a “micro-to-macro” (MM) approach that utilises microeconomic data to produce new insights on the determinants of aggregate productivity and other macroeconomic outcomes. This is summarised along with a discussion of the “three equations” that form the backbone of our empirical modeling.

A DEFINING THE MICRO-TO-MACRO APPROACH

The origins of the micro-to-macro approach can be traced to the key contributions of Davis, Haltiwanger and Schuh (1996) in using employment flows data to analyse patterns of job creation and destruction. Their approach unleashed a wave of research on employment flows and firm turnover during the 1990s and 2000s. This general approach has recently fed into the literature on the economic impact of ICT – e.g. the recent major report by Bartelsman et al (2004). Following the discussions by Bartelsman et al (2002, 2004) and Davis, Faberman and Haltiwanger (2006) there are three themes that underpin the micro-to-macro approach. These themes distinguish the contribution of the micro-to-macro methodology from the contributions feasible using growth accounting (GA) and industry-level econometric (ILE) methods:

1. *Micro-economic Decision-Making at the Firm Level:* By using microeconomic data the MM approach naturally generates an economic framework that is explicitly rooted in firm level decision-making. The key advantage of this approach is that it provides scope for richer dynamics, particularly in relation to policy-relevant parameters such as adjustment costs for firm level investment or employment decisions. One of the prime examples we use in the section below and develop empirically is the firm level modeling of ICT investment – an approach with wide policy applications that has not been explored in the GA and ILE literatures. A further advantage of this focus on microeconomic decision-making is that it provides greater scope for the testing of spillovers. For example, it is impossible to test for within country spillovers using macro data and impossible to test for within industry spillovers using industry-level data.

2. *Firm level Heterogeneity:* This theme relates to how the characteristics of individual firms may affect investment decisions, productivity and other economic outcomes. Since the GA and ILE approaches are premised on aggregation they ignore firm level heterogeneity by definition. Key examples of heterogeneity include firm age, firm size, workforce skills, exposure to international trade, and organisational capital. Macroeconomic outcomes are the aggregation of a distribution of heterogeneous effects and the understanding of this heterogeneity is therefore of obvious importance for informing policy. In section II we will show that organisational capital is a major source of heterogeneity in the impact of ICT on firm performance. Our focus on this topic includes a detailed discussion of our measures of organisation capital as well as a review of the theoretical mechanisms that underpin the complementarities (i.e. the impact of ICT on productivity is much stronger for firms with high levels of organisational capital).

3. *Productivity and Reallocation:* The literature since Davis, Haltiwanger and Schuh (1996) has revealed the substantial role of reallocation in determining overall productivity growth. The international evidence suggests that reallocation is strongly productivity enhancing. That is, market competition implies that inputs and outputs are

reallocated from less productive to more productive businesses in a quasi-Darwinian fashion. In turn, a substantial fraction of aggregate productivity growth is accounted for by reallocation (Bartelsman et al 2004). The importance of reallocation in determining productivity therefore opens up a new window for policy, namely the consideration of the economic forces that impinge on entry, exit and the mobility of factors of production.

The potential for the above themes to inform policy-making needs is considerable – here are four examples. First, many of the factors that micro analysis identifies are complementary to ICT and are sensitive to policy. Better people management and decentralisation can be fostered by stronger product market competition (e.g. the Services Directive) and more human capital. Second, strong positive ICT spillovers would justify for subsidising ICT, whereas weak or negative spillovers would not. Third, modeling firm level ICT investment enables us to identify the impact of demand policies (e.g. the current stimulus programs) and taxes on ICT investment. And finally, an understanding of heterogeneity in the impact of ICT is necessary for informing any policy that seeks to target the behaviour of particular sections of the economy (for example, small-to-medium sized enterprises (SMEs)).

B MODELLING APPROACH

The basic methodology of the report can be summarised in terms of three equations estimated using firm level microdata. The first key equation is the microeconomic **production function** (outlined in section I), which can be extended to incorporate terms for heterogeneity and spillovers. This production function is used throughout the report, notably in discussions of organisational capital and the productivity of multinational enterprises (MNEs). The second equation is the **technology adoption equation** (also first outlined in section I). This equation is the main tool for examining questions related to ICT uptake and, more formally, ICT investment (section I.A). Finally, we also outline an **innovation equation** in section II, focusing on patents (and citation-weighted patents) as the main dependent variable. These three equations are complemented with an employment and exit equation when considering the issue of reallocation. Critically, all of these models are extended with additional terms to measure heterogeneity and other effects such as spillovers. These extensions allow many economic questions to be nested within the same system of equations.

C DATA

The majority of this report is based on the AMATECH dataset constructed at the Centre for Economic Performance (CEP). This database combines establishment-level information on ICT from the Harte-Hanks (HH) Computer-intelligence Technology Database (CiTDB) with company accounts information from the AMADEUS[3] database produced by Bureau Van Dijk (BVD). Establishments in the CiTDB have been matched by name, industry and postcode to companies in AMADEUS. Where multiple establishments have been matched to the same company (ie: multi-establsihment firms) we aggregate these different sites (weighting by site employment) and construct a coverage ratio comparing total HH and total AMADEUS employment[4].

The key advantage of the AMATECH design is that it is based on commerically tested information. That is, since HH sells equipment information to ICT vendors for marketing

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[3] Note that AMADEUS is nested within the global ORBIS database produced by BVD. The ORBIS database covers countries outside of Europe

[4] To be clear, we sum all employment across Harte-Hanks establishments and divide this number by total company employment from AMADEUS. This number will be close to 1 for companies with complete coverage in HH. We use this coverage ratio variable as both a weight and a control in various regressions.

purposes this information needs to be very accurate. The disadvantage here is that HH does not follow an explicit stratified random sampling design in its surveys. This can result in some over-sampling of high-tech firms in smaller countries. The empirical work presented below deals with this by using alternative weighting schemes (eg: by coverage ratio or industry/region level output) and by focusing various sub-samples where data quality and coverage is particularly good.

One practical issue that is central to the empirical work presented in this report is the measurement of ICT capital. Our main measure of ICT capital is PCs per person. This captures the main component of tangible ICT capital and the main results using this measure are found to be comparable to other types of ICT capital measures such as those used by the Office of National Statistics in the UK (see section III for empirical work using ONS data). Furthermore, this report presents some of the first estimates of intangible ICT capital measured at the micreconomic-level. Specifically, this includes purchased software and own-account software, all built up from establishment-level data in the CiTDB. This focus on intangible capital is complementary with out other major data construction effort, namely the CEP International Management Survey (IMS) which provides detailed measures of management practices and organisational structure. This survey and database is discussed in detail in section II.

Finally, note that our data collection effort is complementary with other Commission funded datasets on ICT. First, EU-KLEMs can be matched to our data. KLEMS has the advantage of covering more years, but the disadvantage of quite aggregated industry-level (rather than firm-level) data. Second, Eurostat/ONS have finished a project on 13 countries using National Statistical Office data on establishments. This has the advantage of being matched to confidential statistical office data, but the disadvantage that it is not publicly available and that only two countries have “stock” data on ICT. Nevertheless, most of our findings are consistent with the results on these complementary databases.

I IMPACT OF ICT ON COMPETITIVENESS AND GROWTH

The following Sections on productivity estimation and ICT summarise the core methodologies to be used in the report. Sub-Section A considers a number of important strategies for understanding the impact of ICT on productivity, ranging from microeconomic productivity estimation to an analysis of reallocation of jobs among firms. The following sub-section B reviews the modeling of ICT adoption and diffusion, including many of the hardware and software indicators. The remaining sub-sections cover subsidiary topics in spatial economics; the impact of ICT in the public sector, and the role of ICT in consumer side of the economy. Note that a survey in Appendix C, part VI provides more detail on existing studies of ICT and productivity at macroeconomic, industry and firm-level.

A EMPIRICS OF PRODUCTIVITY AND INVESTMENT

Our main empirical framework for understanding the impact of ICT of productivity, competitiveness and growth is elaborated below in a number of sections. The empirical methods discussed here are used widely throughout the report.

Firstly, we outline the basic approach to firm level productivity estimation that will form the backbone of our empirical work on productivity. The main approach is outlined in the text below while a number of the technical issues are detailed in Appendix A. This sub-section also explains how heterogeneous effects can be incorporated into the production function framework and offers a clear example in the form of UK estimates using the AMATECH data. We also outline how the firm level production function approach we use can be extended to test for the existence of ICT-related spillovers. In brief, this is achieved by defining different "distance-weighted" terms for ICT intensity and adding them as extra terms in the firm level production function. That is, following the literature on R&D spillovers (for example, Griliches, 1992, Jaffe, Trajtenberg and Henderson 1993, and Bloom, Schankerman and Van Reenen, 2009) we define terms that measure the ICT intensity of firms in the same industry or region as a test for potential spillover effects in ICT investment.

Secondly, we offer a framework for modeling ICT investment. This framework is founded on the recent literature on investment modeling (Caballero 1997, Cooper and Haltiwanger 2006; Bond and Van Reenen, 2007, and Bloom 2009) which considers a range of important technical issues such as aggregation, partial irreversibilities, adjustment costs and the impact of uncertainty. As we discuss, these technical issues in the modeling of investments have some useful insights for policy-making.

Thirdly, we discuss the role of ICT for the economics of reallocation. Specifically, we analyse the issue of selection. Our AMATECH data allows us to look at the role of ICT in two types of firm level selection processes. The first is establishment-level exit where we describe the process in which low-tech firms are more likely to be selected out of the economy (known as a "net entry" effect). The second process relates to the reallocation of employment between the surviving incumbent low-tech and high-tech firms. By this we mean the process in which high-tech firms may increase their share of economic activity relative to low-tech firms. Both of these selection processes lead to increases in technological intensity and productivity. We therefore outline a methodology for understanding these selection mechanisms as well as empirical results for 12 European countries in our AMATECH data.

(i) Production Function Estimation

We begin our discussion by outlining the basic neoclassical approach that, in addition to being the most common approach in the literature, also provides a very useful framework for organising our thinking. We show how the growth accounting and microeconomic production function approaches are conceptually linked. Following this review, we show how the production function approach can be extended with extra terms to measure the effects of heterogeneity and test for the possible effects of spillovers.

General Approach

The general approach we use begins with a production function, $F(.)$, which relates output, Y, to a vector of inputs X. One of these inputs is capital; the components of capital are ICT capital C, and non-ICT capital K (which includes non-ICT equipment and buildings). There are also factors of production such as labour L, and materials M[5]. We also allow different levels of efficiency, A (Hicks neutral technology). Consequently, we can define:

$$Y = AF(X) = AF(L,K,C,M) \qquad (1)$$

To further illustrate the issues we will assume that the production function can be written in Cobb-Douglas form (although the results we discuss are suitable for much more general forms of the production function such as Translog or CES). In natural logarithms the production function can be written as:

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[5] As further issues are covered in the report we consider sub-divisions of these broad input categories, for example, the distinction between tangible and intangible ICT capital. Appendix B gives a detailed review of ICT capital measurement while Section II covers intangible ICT capital.

$$y = a + \alpha_l l + \alpha_k k + \alpha_c c + \alpha_m m \qquad (2)$$

where lower case letters indicate that a variable has been transformed into a natural logarithm (e.g. *y* = *lnY*). In discrete time, the growth rate of output (*lnY*) can be written as:

$$\Delta y = \Delta a + \alpha_l \Delta l + \alpha_k \Delta k + \alpha_c \Delta c + \alpha_m \Delta m \qquad (3)$$

where Δa is Total Factor Productivity (TFP) growth and the other terms are the growth rates of the inputs.

From this baseline several analytical approaches are now possible. The first approach we consider is of course growth accounting, which is popular in the macro literature and has been reviewed in the First Interim Report. The second approach is to estimate some form of the production function directly using microdata on firms. Both approaches share the same underlying assumptions although the microeconomic production function approach is much more flexible in terms of relaxing these assumptions[6].

Let us start with a brief outline of the growth accounting methodology. Under constant returns to scale (i.e. $\alpha_l + \alpha_k + \alpha_c + \alpha_m = 1$), we can re-write the growth equation in terms of labour productivity growth:

$$\Delta(y - l) = \Delta a + \alpha_k \Delta(k - l) + \alpha_c \Delta(c - l) + \alpha_m \Delta(m - l) \qquad (4)$$

Therefore, output growth per hour is a function of inputs per hour and TFP growth. Under the assumption that factor markets and product markets are perfectly competitive, the coefficients on factor inputs can be replaced by their shares in revenue. Denoting a revenue share by *s*, we can write:

$$\alpha_x = s_x = \frac{\rho_x X}{PY} \qquad (5)$$

where ρ_x the unit cost of factor *X* and *P* is the output price (so *PY* is revenue). For example, ρ_c will be the Hall-Jorgenson user cost of ICT capital. For labour, ρ_l is simply the wage rate.

Given this, we can re-write the production relation as:

$$\Delta y = \Delta a + s_k \Delta(k - l) + s_c \Delta(c - l) + s_m \Delta(m - l) \qquad (6)$$

Note that, with the exception of TFP growth, Δa all the objects on the right-hand side of this equation are observed. Growth accounting (over a period) divides output growth into the contribution of the (weighted) growth of inputs and the contribution of the residual. Since Solow (1957), the contribution of the residual has generally been found to be large. This is sometimes labeled “technical change”, but obviously it includes everything in the economy that improves (or reduces) the efficiency with which factors are used (as well as some amount of measurement error).

Clearly the contribution of ICT capital will be $s_c \Delta(c - l)$. Note that the value added (V = Y-M) version of the production function is:

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[6] It should also be noted that, technically, growth accounting is possible at the micro level and production function estimation is also feasible at the macroeconomic level.

$$\Delta(v-l)=\Delta a+s_k\Delta(k-l)+s_c\Delta(c-l) \qquad (7)$$

This provides a basic picture of growth accounting. In the ICT literature growth accounting has focused, naturally enough, on the importance of the ICT contribution by decomposing the equations by industrial sector because ICT contributes to aggregate productivity growth in two distinct ways. First, through ICT-capital deepening, $s_c\Delta(c-l)$, as sectors increase the intensity of their ICT use labor productivity will rise. Secondly, through TFP growth in ICT producing sectors (which have played such a prominent role in the post 1995 US productivity acceleration) there will be an additional effect on productivity.

There are several well-known problems with growth accounting methods. In particular, it describes productivity patterns but does not explain them. There is no attempt to claim that there is any causal connection between changes in inputs, such as ICT, and productivity. Furthermore, the assumptions underlying growth accounting are strong and generally not tested (for example, perfect competition). It is simply assumed in growth accounting that the share of ICT capital measures its contribution, and no attempt is actually made to estimate the strength of the relationship in the data. Additionally, if there are externalities related to factors they will be included in the residual, and the contribution of these factors will be underestimated. For example, modern endogenous growth theorists emphasise that there may be important knowledge spillovers from human capital, especially the highly skilled workers employed in the research and development (R&D) sector (see, for example, Aghion and Howitt, 1998, 2009). Consequently, traditional growth accounting will systematically underestimate the importance of these factors in accounting for economic growth (e.g. see Sianesi and Van Reenen (2003) for a survey of the role of human capital in growth). Finally, the model is one of static long-run equilibrium and takes no account of adjustment costs.

Given this background, the alternative approach of microeconomic productivity estimation implements equation (2) in an econometric framework as follows:

$$y_{ijkt}=\beta^c c_{ijkt}+\beta^k k_{ijkt}+\beta^l l_{ijkt}+\gamma' x_{ijkt}+u_{ijkt} \qquad (8a)$$

where the variables *y*, *c*, *k*, *l* again denote the logarithms of real output, ICT capital and non-ICT capital. The *x* term represent a vector of other possible covariates with the subscripts denoting firm *i*, industry *j*, country *k*, and time period *t*. The *u* term is a stochastic error term[7].

Some Econometric Issues – Unobserved Heterogeneity, Endogeneity and Measurement Error

There are many well known problems with estimating econometric relationships such as the production function in equation (8). First, if there is unobserved heterogeneity, the ICT coefficient may be picking up the effect of an omitted factor such as managerial ability. Unobserved firm-specific factors positively correlated with ICT capital will impart an upward bias on the β^c coefficient. Firms with a strong innovative or managerial prowess are likely to invest more in ICT and it is this underlying unobservable factor that is driving the estimated β^c coefficient. In a panel data context (where repeated observations on the same unit over time are available) a classical solution is to assume that this unobserved heterogeneity is broadly fixed over time for a given firm, so we can control for it by looking at growth rates (the empirical

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[7] Note that from this point we suppress the inclusion of materials in the microeconomic production function. This is because it is not a data item generally available in most datasets and therefore not included in most of our production function estimates. We have tested whether this biases our results by looking at sub-sets of the data where we have more information and (1) substituting value added for output as the dependent variable and (2) conditioning on materials on the right hand side of the regression. As with other researchers at the micro level we found that this did not change the qualitative results so we feel confident that the lessons from using output as the dependent variable are robust.

analogue of equation (3)). Formally, we control for the fixed effects by using the within groups (WG) or differences estimator (Griliches and Mairesse 1997).

Even then the modeler is faced with the problem that fixed effects will not deal with the effects of transitory shocks to productivity that may be correlated with the factor inputs. The techniques for dealing with this relate to two types of instrumental variables (IVs) – “internal” and “external”. Internal instruments use panel data techniques to generate instruments usually based on lagged values of the dependent and explanatory variables (e.g. Blundell and Bond, 1998, 2000, Olley and Pakes, 1996, de Loecker, 2007). We explain these estimators in more technical detail in Appendix B. External instruments involve the use of exogenous variation in forces outside of the firm. These forces influence the ICT investment or adoption decision at the firm level and (under certain conditions) this exogenous shift in the investment/adoption decision can be used to trace out the causal impact of ICT on a second-stage outcome variable such as productivity. The most commonly invoked external instruments are “natural experiments”, that is, events that have unintentionally reproduced some of the conditions of a random policy experiment. The paper by Aghion et al (2005) is an example of this approach in the firm level literature – they use the EU’s single market reforms as an Instrumental Variable (IV) for competition. One possible route revolves around the use of country, industry and regional variation. To the extent the regional economic and institutional factors influence ICT investment in a well-defined and exogenous fashion this can also be used to develop credible instrumental variables.

Nevertheless, finding exogenous instruments is extremely difficult, so the empirical results will focus on using OLS and internal instruments. In this report we focus on two strategies for dealing with endogeniety. Firstly, in terms of unobserved heterogeneity we explicitly measure the typical sources of heterogeneity in the form of management practices and organisational structure. To the extent that the inclusion of these variables leads to changes in the ICT coefficient it can be argued that omitted variables bias is being sifted out of our OLS estimates. This approach is extensively deployed in section III-A. Secondly, we use internal instruments as part of the production function estimation in Table I.2 and compare the subsequent results with other methods.

In addition to these endogeniety issues, there are a number of sources of measurement error, which can cause econometric problems. Classical measurement error (where the “noise” added to the “signal” of the true variable is random) will not cause any bias if it is in the dependent variable. However, if it is in the right hand side variables the coefficient on the mismeasured variable is attenuated towards zero. The magnitude of this bias increases when we include fixed effects as the signal to noise ratio is less in the time series dimension. This is likely to be a particular problem for capital variables such as ICT since accurate stock values are difficult to calculate in the absence of prices for different asset types or initial values (as per the perpetual inventory method). To address this problem, it is important to compare differenced variables across different time horizons or alternatively calculate within-groups estimates in terms of “deviations-from-means” and such estimates are presented in Table I.2. Again, another step here is too practically improve the measurement of ICT. In our case, we do this with our estimates of intangible ICT capital in section II as well as the measurement of organisational capital in both sections II and III.

A further measurement problem relates to the fact that the dependent variable in equation (8) is not output but sales deflated by an industry price index. If firms have different prices in an industry then this can cause bias on the coefficients. For example, if more ICT intensive firms have higher prices, then the coefficient on ICT is not the pure effect on total factor productivity, but it also incorporates the effect of ICT on the price-cost margin. In general, this may be exactly the parameter we wish to capture as ICT may raise quality and this will enhance a consumers’ willingness to pay for the firms products and so allow it to increase price cost margins. This indeed was the original interpretation give by Olley and Pakes (1996) to their estimator. If we want to purge this effect, then we have to make some further assumptions. For example, if firms are monopolistically competitive with an iso-elastic demand function we can augment equation (8) with industry output (q^I).

$$y_{ijkt} = \beta^c c_{ijkt} + \beta^k k_{ijkt} + \beta^l l_{ijkt} + \gamma' x_{ijkt} + \phi q^I{}_{jt} \quad \text{(8b)}$$

To recover the structural parameters from the production function (equation (2)) we use the estimated equation in (8b) (e.g. $\alpha_c = \beta^c / (1-\phi)$). This method is detailed in Griliches and Klette (1996) in the single product context and de Loecker (2007) in the multi-product context.

Empirical Findings for Europe and the US

Our main empirical setting for testing the impact of ICT on productivity is a panel of European firms drawn from the AMATECH database. This includes approximately 19,000 firms across 13 countries. This represents the core sample of firms in countries with the longest time coverage (1998-2008) and most complete data. Some descriptive statistics are reported in Table I.1. The median firm size is 140 employees with a mean of just under 400. Average PC intensity is approximately 0.50 (that is one computer for every two employees).

The results for some production function models estimated on this sample are reported in Table I.2a. In this table we use a measure of ICT capital that is constructed as the number of laptops and PCs per worker. This is effectively a hardware-only measure of ICT capital and other measures are tested in subsequent sections. The first column reports the OLS estimates with an estimated coefficient of 0.091 (0.005) on ICT capital. This is a high estimate, suggesting that a 10% increase in ICT capital is associated with a 0.9% increase in output. More pointedly, it is higher than the share of ICT capital in output (which is approximately 1-2% for this sample) and therefore suggests very high returns to ICT capital. The coefficients on labor and total capital are closer to their factor shares and the model is close to constant returns to scale.

A within-groups (WG) specification is reported in column (2). This controls for fixed, unobservable factors prevailing at the firm-level – the omitted variable bias mentioned above that is usually rationalised as some type of unmeasured managerial or technological ability specific to the firm. Practically estimation by WG leads to a lower (but still significant) coefficient of approximately 0.023 (0.003). However, while lower than column (1) this coefficient is still high relative to the share of ICT in output. In contrast, at 0.083 (0.006) the coefficient on capital is low compared to what would be expected from capital's share in output.

The final two columns use the Olley-Pakes and GMM-System methods to deal with the endogeneity arising form the input decisions of firms. These methods produce estimates for ICT capital that are between the OLS and WG results, along with higher capital coefficients (particularly in the case of the column (3) Olley-Pakes specification).

There is no "magic bullet" in dealing with the econometric problems in estimating production functions. The within groups estimates offer the most conservative estimates of ICT, but the coefficients on capital may be biased towards zero due to the problem of measurement error (which will attenuate the coefficients towards zero on the capital inputs that are more "persistent" than labor). The more sophisticated methods are closer to OLS levels which give larger estimates of ICT capital. To be safe and to make sure we do not over-estimate the importance of ICT, we will generally be conservative and prefer our rigorous within groups estimates, but we will also present OLS levels results (i.e. without fixed effects for comparison purposes).

Our new results for European firms given in Table I.2a are interesting in the context of the firm-level literature on the productivity impacts of ICT. The work by Brynjolfsson and Hitt (2003) provides comparable specifications and estimates to those we report in Table I.2. In that example, they use a sample of large US listed firms over the period from 1987-1994. Their estimate of the ICT capital coefficient is in the 0.020 – 0.035 range for the within-groups-style specification reported in column (2). Thus, even using a different (earlier) time period and with a specific type of firm (ie: large, listed US firms) we able to observe a similar finding – high ICT output elasticities and by implication "above-normal" returns to ICT.

We investigate this further in Table I.2b where we directly compare estimates for the US and Europe. In this table we have constructed a US firm-level dataset using COMPUSTAT and following the approach Brynjolfsson and Hitt (2003). However, the data we use here covers the period from 1996-2008. Note here that since COMPUSTAT only contains large, publicly listed firms this results in a smaller sample and limits our ability to investigate heterogeneity. However, despite these differences in samples the estimates in Table I.2b indicate similar ICT capital coefficients for the US and Europe. While the US ICT coefficient is much lower for the US in the case of industry fixed effects (columns(1) and (2)) the preferred within-groups estimates are very close, with a European coefficient of 0.023 and a US coefficient of 0.020. In effect, these estimates are statistically indistinguishable but it is encouraging that the coefficients are so close for two samples so different in their underlying composition. Furthermore, the evidence on within-Europe differences we present in the following tables would seem to indicate that the US coefficient is closer to the UK baseline in our European sample which is consistent with the common institutional features share by the US and the UK. However, we defer the detailed analysis of US-EU productivity differences to our test based on multinationals and management practices in section III. The approach in this later section is a much tighter research design for examining the crucial complementary capital hypothesis.

Arguably, this finding of above-normal is a defining result of the firm-level literature on the impact of ICT. As discussed, one interpretation of these above-normal returns is that they are indicative of the presence of other complementary factors of production that have gone unmeasured. Management practices and organisational structure are the leading example of this type of omitted, complementary factor. The intuition here is of course that these practices and structures are a source of intangible capital that enhances the effectiveness of ICT investments. We return to these hypotheses about complementarity in section II (D).

The most important extension to the above production function framework relates to heterogeneity. It is straightforward to measure heterogeneity in the impact of ICT within this framework. Consider the situation where we are concerned with a characteristic such as firm age, size or sector (for example, the ICT-using sector). We can denote this characteristic generically as *h*:

$$y_{ijkt} = \beta^c c_{ijkt} + \beta^k k_{ijkt} + \beta^l l_{ijkt} + \beta^h h_{ijkt} + \beta^{ch}(c_{ijkt} * h_{ijkt}) + \gamma' x_{ijkt} + u_{ijkt} \qquad (9)$$

The direct effect of the characteristic *h* is measured by the parameter β^h. The effect of the linear ICT capital parameter β^{c} c is therefore augmented by the parameter β^{ch} which measures how the effect of ICT capital varies according to characteristic *h*.

Some examples of heterogeneous ICT effects for our European sample are given in Table I.3. We investigate the heterogeneity of this ICT impact on productivity across firm size, age, time, regions and industries. In Table I.3 column (2) we interact the ICT measure with a dummy for the firm being a small or medium sized enterprise (defined here as less than 250 employees), and find no difference in the return to ICT across firm sizes. In column (3) we interact the ICT measure with a dummy for the firm being "young", defined as less than 25 years since incorporation and again find no significant interaction[8]. In column (4) we interact ICT capital with an dummy variable indicating whether a firm is located in a high-tech region (ie: a NUTS1 region in the highest quintile of the distribution of PCs per person). In the final column we interact the ICT term with a dummy denoting the firm is in one of the ICT intensive industries that Van Ark et al. (2002) report as explaining the acceleration of US productivity growth over European productivity growth. This is an important consideration given that the rapid growth in US productivity since 1995 occurred in the ICT intensive service sector. We find that these industries have an elasticity of output with respect to ICT about twice the size of the non-ICT intensive industries, with this difference significant at the 5% level.

Another important theme underpinning the productivity impacts of ICT is that of spillovers. A spillover is an effect on a firm's productivity of the ICT of *other firms* in the economy (after controlling for the firm's own ICT inputs). The idea of spillovers has been a motivating argument in discussions of the knowledge economy, particularly those relating to the impact of R&D. There are also some natural policy implications related to spillovers. Where the private and social returns to a form of capital differ (with the social returns exceeding private returns) there is a rationale for implementing policies to increase investment. As Griffith (2000) notes in the case of R&D these policies can take the form of direct subsidies; investments in complementary or supply-side inputs (such as human capital); laws to support intellectual property; and investment tax credits.

There is a case that ICT investment could be a source of spillover effects but arguably it is not as clear-cut as with R&D. For example, it is frequently argued that ICT is a general-purpose technology (GPT). This has several implications; first, adoption of a GPT entails experimentation that may lead to innovation by the adopting firms, which in turns shows up as TFP growth. Second, as well as innovating themselves, firms can learn from the (successful or unsuccessful) innovation efforts of others, so there are spillover effects (Bresnahan and Trajtenberg 1995). Thirdly, there may be network effects specific to the widespread use of ICT, that is, ICT may be more effective when many firms in a region or industry are using high levels of ICT.

These considerations cause researchers to look for spillovers from ICT in the same way that researchers looked for R&D spillovers (Griliches 1992; Jaffe 1986, Bloom, Schankerman and Van Reenen 2009). The method generally employed is to augment the production function with a spillover term *SPILL*, which is the ICT of other firms that are "nearby" in economic space:

$$y_{ijkt} = \beta^{c} c_{ijkt} + \beta^{k} k_{ijkt} + \beta^{l} l_{ijkt} + \gamma x_{ijkt} + \mu \ln(SPILL)_{ijkt} + u_{ijkt} \qquad (10)$$

Where the new variable SPILL measures the intensity of ICT usage along a number of possible dimensions. Practically, we are interested in whether μ >0. The main problem here is how to construct the SPILL measure. In general, this requires the specification of weights or 'distances' (d_{ip}) between firms *i* and *p*. So in general – omitting for the sake of simplicity the subscripts j, k and t - we can specify a distance matrix such as:

$$SPILL_i = \sum_{p,i \neq p} d_{ip} C_p \qquad (11)$$

The distances (*d*) could be based on industry – for example, all the other firms in the firm's industry are given a weight of unity (d_{ip}=1), while firms outside the industry are weighted zero (d_{ip}=0). If spillovers come from forward or backward linkages, input-output matrices or trade matrices could be used. Alternatively, weighting can be based on geography or technology

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[8] We also investigated other cut-offs of the size and age thresholds which also did not produce any significant interactions.

class. It should be emphasised however that ICT, unlike R&D, is generally embodied and knowledge spillovers may be a priori less likely. Network effects may be more important, but these might apply to specific forms of ICT (like operating systems or communication networks) rather than ICT in general. Practically, network effects are more relevant in the case of technology adoption and we look at these effects in more detail in section I –B.

These observations are borne out by the estimates in Tables I.4(a) and I.4(b), which continues the analysis of the European AMATECH data. In these tables we define two types of spillover terms based on industry and regional distance weights – a common strategy in the literature on R&D spillovers. In Table I.4a we concentrate on region-level spillovers, constructing a measure of weighted ICT-intensity for each NUTS1 region. Column (1) shows an OLS specification with SIC4 industry (four digit industry) fixed effects. These SIC4 effects are useful in controlling for the industrial composition of regions and ensuring that the REGSPILL term is identified solely from spatial variations. While column (1) shows some evidence of strong spillover effects (with a coefficient of 0.225 and standard error of 0.007 this effect disappears once NUTS1 regional effects are included. The inclusion of these effects in column (2) is intended to control for the fixed unobservable characteristics of regions – for example, the level of human capital or innovative activity in an area. Regions that are intensive in ICT are also likely to have high levels of human capital or patenting activity and we want to distinguish the potential spillover effects of ICT from these other factors. The regional fixed effects specification in column (2) is therefore more demanding in the sense that ICT spillovers are identified via the time-variation in regional ICT intensity. In column (3) we add firm fixed effects which does not change this result. In column (4) we weights by the number of observations in the spillover cell as small cells may will have larger sampling variation. The spillover coefficient is positive but miniscule (a doubling of ICT in the region increases Productivity by one tenth of one percent) and is statistically insignificant.

Table I.4(b) implements a similar test for region-industry spillovers defined at the NUTS1-SIC2 level. The REGSIC term therefore represents a spillover term that is more likely to capture firms closely located in terms of their spatial and industrial distance. In this case, there is some evidence of a small spillover effect remaining after controlling for regional by industry fixed effects in column (2). Even in this case the SICSPILL coefficient falls by two-thirds from 0.095(0.013) to 0.034 (0.015). Furthermore, this spillover effect disappears when firm-level fixed effects are included in column (3) and this is not improved by weighting by cell size in column (4).

Taken together these results suggest there is not strong evidence of substantial spillovers from ICT, in line with the general literature on physical capital which reports little evidence of spillovers rather than the R&D literature which finds strong regional and industrial knowledge spillovers[9]. It is consistent with the evidence in Stiroh (2004) that finds no robust evidence of ICT spillovers in US data. In terms of theory the absence of spillovers for ICT is not such a surprising result. When firms purchase ICT capital they are investing in a form of existing, embodied technology. In contrast, R&D expenditure represents a highly uncertain investment in an activity that may create knowledge and innovation in the future. Other firms are then able to benefit from this R&D through imitation, adoption or the development of further related innovations without necessarily paying a large cost to the R&D performing firm. Since ICT investment is based on existing, embodied technology and knowledge there are fewer channels for such spillover mechanisms to operate. This is an important consideration to be taken account of when framing government policy towards ICT. The traditional rationale for R&D subsidies and tax credits has been that a divergence between the private and social returns of R&D justifies some government intervention to increase investment.

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[9] On R&D spillovers see, for example, Griffith (2000).

Cross-Country Heterogeneity in the Impact of ICT

A major issue highlighted in the existing growth accounting and industry-based literatures on the impact of ICT is the differential impact of ICT across countries. These contributions have concentrated mainly on how cross-country differences are determined by compositional differences, particularly the relative contributions of the ICT-producing and using sectors (eg: van Ark et al 2008). Cross-country comparisons using firm-level data are relatively rare and using AMATECH we are able to present some results for the major European economies in Tables I.5 and I.6. These tables directly extend the specifications for the sample of firms analysed in Tables I.1-I.4. A major caveat here is that in the absence of a set of well-defined causal estimates the impact of ICT the cross-country results here will reflect the different forces underpinning the endogeneity between firm performance and ICT investment. Also, to the extent to which sampling differences cannot be controlled using weights and industry controls some country differences may be the result of non-random sampling rather than objective between-country differences.

In Table I.5 we include interaction terms to pick up the potentially heterogeneous impact of ICT across different countries. These heterogeneity terms provide some useful results. The columns follow the sequence of successively adding more detail controls and observing the effect of these controls on the country interactions. Using the UK economy as the baseline case we can see that the other European economies have a significant lower ICT coefficient across columns (1)-(3). This effect is persistent as we add more detailed industry controls (ie: moving from 2-digit to 4-digit controls) and ranges from around -0.05 to -0.10. Note that in most cases the interaction coefficients for different countries are not statistically different. That is, the main difference in this sample is between the UK and other European countries. In column (4) we add additional interactions between the country dummies and the labour and capital terms in the production function. This is done to ensure that the country heterogeneity being detected is unique to ICT rather than reflecting a general relationship across all firm inputs.

The next column (5) then adds some controls for MNE status and firm size as an additional set of compositional controls. The MNE status control in this case is particularly important since the UK baseline case in these regressions features the highest proportion of MNEs across countries in the sample. Therefore, the higher UK coefficient could simply reflect the presence of these types of firms. This makes a limited difference but in overall terms the addition of observable controls across columns (2)-(5) only manages to chip away around one third of the interaction effects seen in column (1). The final column (6) adds firm fixed effects as the toughest test of country heterogeneity. The addition of fixed effects takes account of unobserved firm-level differences and column (6) shows that most of the country heterogeneity in the impact of ICT is wiped out by the addition of these controls. Hence, the main message of Table I.5 is that cross-country differences at the firm level can mainly be explained by the pattern of unobservable characteristics among firms such as their human, intangible or firm-specific capital. In terms of “country effects” this pattern of unobservables can matter for policy if they are systematically related to country-level institutions. For example, labour and product regulations can influence the way that firms are able to combine their complementary firm-specific inputs with ICT, thereby affecting the estimated returns.

Following this approach, the results in Table I.6 explores whether country differences can be meaningfully explained in terms of the level of labour and product market regulations in each country. That is, we interact a range of indexes of regulation with the ICT capital variable to see if the country heterogeneity of Table I.5 is consistent with differences in these institutions. In columns (1)-(4) we look at two indexes of labour market regulation from the World Bank regulation database. Both measures – an index of dismissal law provisions and a general index of overall employment protection – display significant negative interactions with ICT. These negative effects disappear when including firm fixed effects but to some extent this can be expected since the firm effects control for so many unobservable factors. A similar negative interaction effect is found for the OECD index of product market regulation in column (6) but notably this effect is approximately one-fifth in magnitude compared to the labour market effects in columns (1)-(4).

As noted, caveats to these results remain in terms of endogeneity and potential non-random sampling. However, the results provide support to the idea that country-level factors (such as labour and product market regulation) shape the overall impact of ICT in terms of firm productivity. In section III we return to this issue by presenting a much tighter test of this type of hypothesis. Specifically, we follow the research design of firstly measuring firm-level unobservables directly (ie: by using data from our CEP International Management Survey) and secondly using multinationals as a testbed for examining differences in the links between ICT and other complementary, firm-specific inputs. Insofar that these later results are also linked indirectly to labour and product market regulation they are consistent with the results in Tables I.5 and I.6.

(ii) ICT Investment Equations

General Approach

There is relatively little work on modelling ICT as an investment but understanding this is crucial for thinking about policies to influence ICT adoption. For example, the magnitude of the impact of ICT tax policies will depend on the elasticity of ICT with respect to its user-cost of capital. We start by generating an ICT investment series from first differenced logged ICT capital stocks using the approximation $\Delta ln(C_{it}) \approx \Delta C_{it} / C_{it-1} = I_{it}/ C_{it-1} - \delta$, where δ is the rate of ICT depreciation and I is investment in ICT capital.

We estimate a reduced-form ICT investment specification following Bloom, Bond and Van Reenen (2007), who show this is a parsimonious way of modelling an underlying structural investment equation in the presence of extensive aggregation. Our ICT data will encompass extensive aggregation, due to aggregation over time (the data is only recorded yearly), over establishments (many firms have more than one site) and over activities (even within many establishments different types of activities and production lines will often exist). In this situation a robust reduced form specification is preferable to imposing a misspecified structural model. Following Bloom, Bond and Van Reenen (2007) we include four terms in the specification as follows:

$$\Delta \ln(C_{ijk,t}) = \beta_0 + \beta_1 \Delta \ln(C_{ijk,t-1}) + \beta_2 \Delta \ln(Y_{ijk,t}) + \beta_3 \Delta \ln(Y_{ijk,t})^2 + \beta_4 (\Delta \ln(Y_{ijk,t-1}) - \Delta \ln(C_{ijk,t-1})) \qquad (12)$$

where $\Delta ln(C_{ijkt-1})$ is the lagged ICT investment rate picking up the dynamic effects of adjustment costs[10]; $\Delta ln(Y_{ijkt})$ is the sales growth rate (the standard accelerator term) picking up the instantaneous response to demand and productivity shocks; $\Delta ln(Y_{ijkt})^2$ the sales growth rate squared term picking up the impact of partial irreversibilities under aggregation; and $ln(Y_{ijkt})- ln(C_{ijkt})$ is an Error-Correction Mechanism (ECM) term picking up longer run co-integration between ICT and sales. In a standard model with no adjustment costs and constant homogeneity in ICT capital and output, after controlling for firm fixed effects, we would expect to obtain $\beta_1 =0$, $\beta_2 =1$, $\beta_3 =0$ and $\beta_4 =1$.

Empirical Results for Europe

Table I.5 shows the results of implementing equation (12) using the European AMATECH sample established in the previous tables. Note that in this case the more stringent data demands of the investment equations prevent a detailed analysis of cross-country

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[10] As shown in Cooper and Haltiwanger (2006) and Bloom, Bond and Van Reenen (2007) quadratic adjustment costs and partial irreversibilities generate a positive lagged dependent term while fixed costs generate a negative lagged dependent term. Hence, this term (like all the other reduced form regression coefficients) will be a function of the mix of the underlying adjustment costs.

differences[11]. In Table 5 column (1) we estimate our preferred investment specification using within-groups and find evidence of ICT-related adjustment costs with a significant ECM term. The second column estimates the same type of equation using a (t-2) lag but does not find evidence of adjustment costs or error-correcting behaviour. One consequence of Within-Groups estimation in this case is that it generates a downward bias on the lagged dependent variable of order 1/T, so the zero coefficient on the lagged dependent variable is not particularly surprising (see Nickell, 1981). To benchmark these coefficients column (3) estimates a physical capital investment equation. This is a helpful comparison because we have a much better feel for the responses of physical capital, its implied adjustment costs and cost of capital elasticity from the investment literature[12]. Comparing ICT and physical capital investment in columns (1) and (4) we find there is a significant difference in the ECM terms. At a coefficient of 0.463(0.021) the ECM term is almost one-third larger than the physical capital ECM in column (3). This suggests that ICT capital could potentially respond more quickly to changes in the user-cost of capital, such as those induced by investment tax credits.

In columns (5) and (6) we re-estimate these ICT and physical capital investment equations using GMM to deal with the endogeneity of the investment decision. We find the lagged dependent variables and ECM term are similar to their within-groups counterparts while the sales squared term is positive suggesting substantial partial irreversibilities. Interestingly, again the coefficients on the right hand side variables in the ICT capital are larger than for non-ICT capital, suggesting again a faster response of ICT to external stimulus. This also suggests that the physical capital elasticity - estimated at around -0.5 (see Caballero, 1997 and Chirinko, Fazzari and Meyer, 1999) – may be a sensible lower bound to use for ICT in the absence of any good estimates directly from ICT data.

(iii) Reallocation

General Approach

The issue of reallocation is centrally important to the determination of aggregate productivity trends. The basic intuition explaining the importance of reallocation is two-fold. Firstly, productivity can change due to compositional effects, that is, new firms enter and old firms exit thereby changing the distribution of the micro-units that “add-up” to a total industry or economy-wide productivity figure. This “net entry” effect is reinforced by a further “between firm” compositional effect among continuing firms. The between firm effect is based on the relative size of firms (measured in terms of employment or output) and the subsequent share of individual firms in determining overall productivity. Secondly, this change in composition is non-random and reflects the effects of selection – low productivity firms are more likely to reduce their employment or output (between effect) and also more likely to exit (net entry effect). This process of reallocation can be summarised in an accounting decomposition (e.g. Bailey, Hulten and Campbell 1992). Typically, decompositions such as this indicate that the total effect of reallocation is large with the between and net entry effects each accounting for approximately 25% of total TFP growth (Davis, Haltiwanger and Schuh 1996, Bartelsman et al 2002).

While the literature has clearly documented the role that productivity plays in determining selection, it has not explored the role of technology in this process to the same extent. Productivity and technological intensity are likely to be highly correlated, and the analysis of the production function in sub-section I(i) will examine the strength of this correlation.

To examine the increase in aggregate technological intensity (e.g. ICT intensity) we can consider several dimensions, following the productivity literature. First, there is the within firm

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[11] In particular, these equations are conditions of firms with at least 4 years of non-missing information on ICT and capital which reduces sample size.

[12] See, for example, Caballero (1997).

increase in ICT intensity that was the focus of the previous section. But the reallocation effects constitute an additional "between firm" element. If ICT intensive firms are more likely to grow faster and less likely to exit, aggregate ICT intensity will also tend to increase as a larger fraction of economic activity is allocated to such high-tech firms. The AMATECH data being used in this report allows us to consider in detail these two dimensions of reallocation - establishment exit and between firm changes in employment[13]. Specifically, this can be done using two equations for employment growth and exit. First we consider an equation for establishment-level employment growth:

$$\Delta \ln(N)_{ijkt} = \gamma_b' \Delta x_{ijkt} + \delta_b' x_{ijkt-5} + \theta_b (TECH)_{ijk(t-5)} + v_{ijkt} \tag{13}$$

Where $\Delta \ln N$ represents the change in log employment at the establishment level over a long period (in the following analysis we use 5-years as the time window). The *x* vector here represents a set of establishment and firm level characteristics with δ_b measuring the effect of these characteristics when they are specified as baseline or initial levels and θ_b measuring their effect when specified as changes over the same 5-year window as the change in employment[14].

The available variables in the *x* vector that we will consider include firm size (employment, sales), the firm level average wage and capital intensity (i.e. capital per worker or the capital-sales ratio). The main variable of interest is of course TECH, specified here in terms of the initial or baseline period. TECH represents a measure of establishment-level ICT intensity such as ICT capital, PCs per person or the presence of advanced e-Business software systems. We expect a positive sign on the TECH coefficient since it is more likely that high-tech firms will grow faster than low-tech firms, leading to between-firm selection. The empirical questions then are firstly how important the TECH variable is to the overall between-firm employment effect (ie: what is the magnitude of the θ_b parameter) and then secondly whether TECH has a significant effect even after controlling for the other firm level characteristics such as wages or labour productivity.

The second exit equation is exactly analogous to the employment equation above. We can specify this equation as follows:

$$Exit^*_{ijkt} = \delta_e' x_{ijkt-5} + \gamma_e' \Delta z_{jkt} + \theta_e (TECH)_{ijk(t-5)} + v_{ijkt} \tag{14}$$

where *Exit** represents the propensity of a firm to exit between time *t* and baseline period *(t-5*). This could be estimated by probit, logit or OLS depending on the assumptions we make over the error term. Note that (unlike the employment equation) only the baseline levels of the full *x* vector are included in this specification. This is because including changes in the x vector characteristics presupposes the survival of the establishment between *(t-5)* and *t*. We can still identify sub-components of *x* (called *z*) that are at a higher level (e.g. industry-level factors such as the growth in trade competition from China). The interpretation of the parameters here is then analogous to the employment equation – we are interested in the magnitude of the θ_e coefficient. As with the employment equation we will also be interested in the heterogeneity of the effect of ICT on growth and exit. For example, does increased competition with low wage countries like China increase exit substantially more for low ICT intensive firms that for high ICT

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[13] Our empirical research indicates that establishment exit can be reliably inferred in the Harte-Hanks (HH) data by the disappearance of establishments from the HH survey. Entry is much harder to determine cleanly in the first HH data since the first appearance of a site in the survey could be a function of increased sample coverage rather than the "birth" of new establishment.

[14] Note that the *b* subscripts (for "between firm") are included to differentiate the parameters from similar parameters in the next exit equation.

intensive firms? If so, this suggests that ICT offers some “protection” against increased trade competition from emerging economies, which is an important message for policy makers.

Empirical Results for Europe

Some results for the employment equation are presented in Table I.6. We estimate the employment equation described above for the 12 countries in AMATECH with the longest time coverage (i.e. from 1998-2008). The dependent variable is formulated as the 5-year change in log employment and in the regression we pool this information across a number of waves. That is, we pool together 5-year changes for four windows that end in 2005, 2006, 2007 and 2008. The main variable of interest is the baseline technology measure, here specified as computers per worker in initial year. Panel (A) in Table I.4 shows the results for specification that only use the Harte-Hanks establishment data without conditioning on an AMATECH match. This panel shows evidence of a strong and highly significant selection effect, even after including 4-digit industry fixed effects (column (2)). The third column in Panel (A) then divides the PCs per person measure into five equal quintiles. This quintile specification shows that the effect of PC intensity is clearly monotonic – rising as we move up the quintiles from low-tech to high-tech establishments. The effect is also large – an establishment in the highest quintile experiences a 34.7% higher employment growth rate compared to the low-tech or base case establishment. The results in Panel (B) condition on a match with AMATECH and include a measure of both the company-level wage and labour productivity. Despite the reduced sample (due to missing or incomplete accounts information in AMADEUS) the coefficient estimates for the PCs per person variable are virtually unchanged.

Table I.7 shows a set of qualitatively similar results for exit. In this case however the effect of the continuous ICT intensity is slightly different. First, controlling for industry heterogeneity is extremely important (compare columns (1) and (2)) because exit rates vary dramatically by sector. Second, there is not a monotonic increase in the quintiles which are statistically similar. This implies that the big difference is whether a plant is in the bottom 20% of the ICT distribution or not. These plants are at a much bigger risk of exiting the industry: about three percentage points higher. This is a substantial effect as the exit rate for all establishments existing in 2000 or 2001 was 23% over the 2000-2008 periods. Controlling for various other factors such as wages and productivity makes rather little difference to this conclusion. The ICT effect is not simply a skills or productivity effect in disguise.

Country Heterogeneity in Reallocation for Europe

In order to analyse country heterogeneity in reallocation we focus on the employment equations. Uncertainties in the sampling design of the Harte-Hanks surveys limit the ability to make tight country comparisons since some countries can over-sample high-tech firms in baseline years[15]. However, the insights of the employment equation can be extended to the case of exit. In Table I.10 we include individual country interactions in the employment equation again using the UK as the baseline case. These results indicate that the ICT selection effect is systematically lower for all other countries, in particular Finland, Austria and Switzerland. This difference is only partially reduced when including more detailed SIC3 and SIC4 industry controls. Note that in this case since the dependent variable is in long difference form we have already taken into account firm-level unobservables.

This country heterogeneity is explored further in Table I.11 where we test the effects of country-level indicators of labour and product market regulation. The results of this exercise are consistent with the earlier regressions for labour productivity. Higher levels of labour regulation and product market regulation at the country-level have the effect of lowering the ICT selection effect. The general Labour Regulation index is associated with a one-third lower selection effect

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[15] That is, we found that there was some over-sampling in large countries. In cases where these firms were not followed up in later years this lead to downwardly biased effects of ICT in the exit equation.

while the Product Market Regulation index lowers the selection effect by almost one-fifth. The Dismissals provision index in this case has no effect with respect to selection on the basis of technology. Practically, the magnitude of the coefficients for column (1) indicate that at a firm at the median value of PC intensity grows 6.6% faster over 5 years than a firm at the 25th percentile and this effect is offset by -2.2% at the mean value of the labour regulation index. Similarly, column (5) on product market regulation suggests that the median firm grows 6.4% faster with -1.3% offset at the mean value of the PMR index.

Overall, these effects indicate that the selection effects of ICT are more muted in countries with higher levels of regulation. In turn, this means that the process of reallocation is less effective – low-tech firms have more scope to survive in these environments and this will have the effect of retarding productivity growth. While selection effects based on technology are operating in these environments the gradient of selection is less steep.

Comparison to Other Estimates in the Literature

We have surveyed the existing work on productvity in Appendix C. Exact quantitative comparisons are somewhat hazardous as different studies use different measures and methods (including sample years, industry coverage, firm size, and other covariates). Nontheless, a number of remarks can still be made in relation to the literatures on growth accounting, firm-level productivity, and reallocation.

The results of the above firm-level analysis complement some of the ideas raised in the growth accounting literature (Jorgenson et al 2008, Van Ark et al 2008). In particular, Van Ark et al (2008) raised the prospect that US-EU productivity differentials in the ICT intensive sectors could be related to different regimes of labour and product market regulation. This type of association is confirmed in our firm-level analysis, both by the country-level interaction terms we include in a number of specifications and by the analysis of organisational capital that follows in Sections II and III. Part of the significance of our firm-level results lies in the fact that we have identified organisational capital (and the policies associated with the development of this type of capital) as the *main source* of heterogeneity in our production function estimates. Other types of heterogeneity (such as firm size, age or region) did not seem to affect the relationship between ICT and productivity.

Furthermore, the results in Section I can be considered in terms of the existing firm-level production function literature. First, our results are consistent with the finding that ICT has a positive and significant association with productivity. Second, the magnitude of this effect is larger than would be expected from the relevant ICT share of revenues. This is also a general finding of the firm level literature and motivates the discussion of complementarities. Third, the existence of important complementarities is consistent with other papers in the literature, although we have taken our search for these much wider. Fourth, the absence of spillovers in the production function is also consistent with the general literature.

Meta-studies such as Stiroh (2004) of the hundreds of papers find a coefficient on ICT of around 0.05 (with a huge range between 0.25 and -0.06). Our main within groups coefficient is smaller than this – around 0.023 in the preferred specifications. Some of the other estimation techniques (such as the Olley and Pakes results give a larger coefficient, 0.06, closer to existing papers, but such techniques are not attempted in other papers). We are reluctant to read too much into this difference given the standard errors, but our estimates could be smaller because: (i) our data is higher quality and/or (ii) we have a somewhat narrower definition of ICT than is used in most other papers (e.g. we do not include software or spending on mainframes/servers).

There is a growing literature on reallocation, but we are the first (to our knowledge) to focus on reallocation specifically related to plant level ICT. Our finding that reallocation forces differ between countries is consistent with recent work by Bartelsman, Haltiwanger and Scarpetta

(2004) who find that the process of reallocation is weaker in countries that have stronger levels of labor and product market regulation (e.g. Continental Europe) compared to less heavily regulated nations (like the UK). The large magnitude of the reallocation effects are consistent with much recent work that has found that reallocation is an important factor driving aggregate productivity growth (e.g. Foster, Haltiwanger and Syverson, 2009).

ICT, Productivity and the Japanese Economy

Firm-level ICT information is not available via our Harte-Hanks data so the conclusions here need to be based on existing information from databases such as EU-KLEMS. Fukao and Miyagawa (2007) provide an analysis of ICT investment, labour productivity and TFP in Japan. Many aspects of this analysis are consistent with the themes established in our firm-level research.

Fukao and Miyagawa (2007) find that the Japanese economy experienced the same levels of TFP growth as the four major EU economies (Germany, France, the UK and Italy) in the post 1995 period. While TFP growth in the electrical machinery and communications sector in Japan was higher than both the EU and US this sector was not large enough in size to drive total TFP growth. In particular, the Japanese economy suffered severe declines in TFP in distribution services (retail, wholesale and transportation) and the remaining parts of manufacturing. Fukao and Miyagawa (2007) also found that productivity *levels* were low in market services and the goods-producing industries.

ICT investment was also sluggish in Japan and the contribution of ICT capital services to output actually declined after 1995. This poor performance in ICT investment is seen as one major reason for slow TFP growth. However, Fukao and Miyagawa (2007) also identify another potential reason in the form of intangible investment. They find that despite the high skill levels of Japanese workers the ratio of intangible-to-tangible investment is still low – approximately 0.5 compared to 1.2 for the US.

This finding raises the issue of organisational capital as a complement to ICT investment. Analysis of management practices that we presented later in the report (see sections II and III, particularly Figures 3a and 3b) indicate that while Japanese firms have strengths in monitoring and target setting they are relatively weak in people management practices. The most likely explanations for Japan's diffident performance are therefore a combination of "lopsided" organisational capital (ie: too great a focus on operations) and also product market regulation in the market sector.

B DRIVERS AND OBSTACLES TO ICT ADOPTION

The methodology of identifying and analysing determinants of ICT adoption is vast. Roughly speaking, there are three established (and one emerging) streams of research: The macro-diffusion approach, the micro-adoption approach, the micro-timing approach and the macro-intensity approach. In this project, we employ a combination of these approaches to get a detailed picture of the ICT landscape of US and European firms. These diffusion models will be applied to two main classes of ICT, firstly, PC intensity (i.e. the number of computers per employee) as a broad measure of technological intensity, and secondly individual hardware and software components. Another important aspect of the hardware and software adoption decision is how it is linked to the economic objectives and characteristics of a firm. In later parts of the report we discuss how particular decisions about equipment adoption can be linked to particular economic functions, for example, product and process innovation (section II.B); collaborative activity (section II.C); and firm organisation (section II.D).

(i) Macro-Diffusion Approach

The diffusion approach makes use of aggregate information about the degree of penetration of a certain technology within the economy or a specific sector of the economy. This method has been refined over the past years and uses a large number of techniques taken from both the marketing (e.g. Bass, 1969) and economics literature (e.g. Griliches, 1957). By far the most frequently used regression approach is the logistic curve as used, for example, by Grajek and Kretschmer (2009). When looking at diffusion phenomena at the aggregate level, the basic premise is that the spread of a technology throughout the economy follows an s-shaped curve and eventually approaches its maximum penetration level, which is reflected in the following nonlinear regression equation:

$$DIFF_{kt} = \frac{ADOPT^{*}}{1+\exp(-\beta(t-\tau))},$$

where $DIFF_{kt}$ measures the change in the adoption levels of a technology between period t and $(t-1)$ and $ADOPT^{*} = \gamma POP_k$ denotes the number of eventual adopters as a proportion of the population in country k. We are especially interested in the estimates of β, γ and τ. The parameter β indicates the diffusion speed, i.e. how quickly the economy approaches its maximum penetration, τ is a positioning parameter indicating the "inflection point" of the diffusion curve, and γ is the likely proportion of long-term adopters of a given technology. We derive diffusion parameters on the PC intensity – i.e. the number of PCs per employee in a firm.

To facilitate comparison, we focus on the manufacturing sector only[16]. Results of our country-level nonlinear least squares estimations are presented in Table I.12. The τ and γ parameters are significant in our estimation, while the parameter measuring the speed of diffusion, β, is not. While this is disappointing as the speed of diffusion seems a key parameter of interest, it is also in line with Comin et al. (2006), who find that measures of the intensity of technology use do not fit well with logistic diffusion functions. As the number of PCs per employee is not a measure of extensive diffusion (ie: how many firms use PCs), but also of usage *intensity* within the firm, the inconsistent results on diffusion speed may not indicate specification issues. Instead it may be indicative of greater heterogeneity in usage intensity than in patterns of first adoption. Despite these caveats we estimate logistic diffusion functions because they represent a benchmark for technology diffusion patterns.

The parameters indicating the ceilings of adoption are fairly heterogeneous and indicate higher long-term penetration rates in Scandinavian countries and to an extent the UK. The estimates measuring the inflection point indicate fairly similar inflection points across countries except for the cases of Austria and Norway. From Table I.12 we can see that several countries, namely Austria, Norway and Sweden, are at or even above their imputed maximum level of penetration. On the other hand, some countries still show significant growth in PC penetration in 2008, suggesting that penetration will continue to grow for some more years.

Interestingly, when running diffusion regressions at the EU level and comparing it to the US regressions (the final two columns of Table I.12), we obtain a faster diffusion parameter for Europe than the US, albeit a lower long-term penetration rate. Combined with the fact that European penetration in 2007 is actually above the imputed long-term penetration rate, this suggests that European firms will not continue to expand their ICT use by much (if at all), while diffusion in the US is still considerable at this time and will continue to be for the following years.

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[16] We also experimented with weighing results per country by the relative importance of a particular sector in that country and found qualitatively similar results.

In any case, while describing the diffusion patterns across countries is an interesting exercise, in previous studies these results may have been given excessive attention. The analytical contribution of these results is fairly limited however since the actual process behind these diverging adoption patterns is not clear. Despite restricting the industry coverage to manufacturing industrial composition may still be playing a role in driving the results. Thus, given the increased availability of data at the micro (i.e. establishment) level, it seems sensible to focus on the drivers and obstacles of ICT adoption at the firm level. This will allow us to identify firm, industry and country characteristics that may affect the spread of new technologies throughout the economy.

(ii) Micro-Adoption Approach

The micro adoption approach disaggregates the diffusion curve and is particularly useful for identifying the sources of differential adoption by firms. The so-called rank (or probit) effect postulates that firms (or households) have different preferences for a new technology. The generic microeconomic approach we take to modeling adoption involves the specification of a technology adoption equation:

$$\Pr\left(y_{ijklt}=1\right)=\beta x_{i(t,t-1)}+\beta x_{jt}+\beta x_{lt-1}+\delta_j x_j+\delta_k x_k+x_t+\alpha_i+u_{it}$$

Where *y* is a technology outcome that can be expressed as a discrete or continuous indicator (here, we have put forward the discrete version).The x's represent the following vectors of variables:

x_{it}	firm specific and time varying observables (Employees, PC Intensity, ICT Employee intensity),
x_{kt}	time varying country specific observables (eg: GDP per capita),
x_{lt}	time varying regional specific observables (NUTS1 penetration),
x_k	time invariant country dummy ,
x_j	time invariant sector dummy,
α_i	firm specific error term,
u_{it}	idiosyncratic error term.

In the sub-sections below we first model PC adoption as a simple, "general" measure of ICT and then consider the adoption of specific pieces of software and equipment.

General PC Adoption

The first area of firm-level ICT adoption that we examine is PC adoption. This is useful as a general measure of the level of ICT used at the firm-level. Specifically, we measure PC intensity, that is, the number of PCs per person employed at the firm. This measure also has the advantage of being a continuous measure that is complementary with the adoption of other types of ICT equipment[17]. In our first set of estimates (presented in Table I.13) we look at the role of firm-level characteristics in determining the adoption of PCs and divide the results between manufacturing and services. These models are estimated at the establishment level and conditioned on the sub-sample that is matched with the AMATECH company-level accounts information.

It is clear from Table I.13 that firm size (measured as the number of employees) has a negative correlation with PC intensity which probably reflects division bias (employment is in the denominator of the dependent variable). The number of ICT staff has a strong positive association with PC intensity and the coefficient for this variable falls when industry and region

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[17] For example, as we show in later tables, the adoption of firm-wide software technologies can depend on the existence of dispersed PC resources in the firm.

fixed effects are included. The third column in each panel includes AMATECH company-level variables measuring the average wage and sales. The wage variable is positive and significant – this is consistent with prior expectations in the sense that wages are a useful proxy for skill. Interestingly, the ICT staff variable is still significant even after including wages, indicating that it (i.e. ICT staff) has explanatory power over and above its correlation with skills. Multinational status is associated with more PC intensive establishments to a large degree with almost 10% more computers per employee. This is large considering that by comparison the coefficient on wages indicates that a 10% increase in the mean wage is associated with around a 1% increase in computers per head.

The next PC adoption question we consider is the extent of cross-country differences in adoption rates. Specifically, we are interested in the question of whether there are any significant differences in PC intensity between countries after taking account of industry composition and regional fixed effects. The regional fixed effects are important here because they will control for important factors that vary on an intra-country basis. These include important determinants such as human capital and physical infrastructure. What is left then for the country dummies are the residual country-level factors that are uniform across regions such as labour or product market regulation. We consider this strategy in Table I.14. Here we have defined "bloc-level" dummies where we have pooled similar countries in order to avoid low sample sizes for the smaller countries. The definition of the blocs was chosen on the basis of geography and/or historical close associations between countries. The omitted category is the Eastern European bloc of countries.

The results suggest that there is a significant difference in adoption between Western and Eastern Europe. Western Europe has on average 2 more computers per 10 employees than Eastern Europe. However, when we examine the exact coefficients it becomes clear that there are very limited differences within Western Europe. The coefficients for different Western European bloc dummies are close together in value, such that even in cases where the differences are statistically significant the magnitude is small. The only significant differences are a moderate Anglo bloc advantage in financial services and a higher PC intensity for the Germanic bloc's retail and wholesale sector. These are important results in the context of the overall findings of report. That is, it seems that cross-country differences in ICT-related productivity may be driven by the presence of complementary factors (such as organisational structures or management practices) rather than the level of technology per se.

Software Adoption

Another important area of technology adoption involves the adoption of specific pieces of ICT software or equipment. In our regressions we estimate the probability of a firm adopting a technology at a given time *t*. Note that this is not equivalent to measuring the *timing* of first adoption, which is captured more adequately by the hazard rate approach reported in the following section.

We chose our two technologies for a number of reasons: First, DBMS and ERP represent advanced information technologies used predominantly by enterprises. They are flexible and customisable and are therefore used by a wide variety of different firms. Second, there are also significant differences between the technologies. Database management systems (DBMS) are typically bought "off-the-shelf" and customised, adjusted and updated within the firm, while ERP adoption often represents ongoing projects requiring significant input from outside consultants who customise an ERP for the firm in the installation phase. Third, they were at different points in the diffusion process during our study period. While DBMS had already diffused throughout most of the economy, aggregate usage of ERP was still relatively low. Thus, by studying both software types and focusing on the differences in results between the two, we hope to gain valuable insights about firm behaviour at different stages of a technology's life cycle.

One extra focus we introduce here is the potential for peer or network effects in adoption. That is, we ask whether the probability of adoption is influenced by adoption rates among similar or neighboring firms. This is implemented using regional penetration variable calculated as a simple average of the dummy variable representing the software technology. For this, variable firms of all sectors were used. It seems plausible that after controlling for industry-specific effects through sector dummies regional spillover effects are likely to operate across industries. In terms of mechanisms, regional spillover or network effects could work along the supply chain as firms seek to achieve compatibility with their suppliers and/or buyers.

One-year lags of the independent variables are used to mitigate on simultaneity problems. We report both the pooled and the RE estimations in the tables in this section and run regressions for the adoption of database management software (DBMS) and enterprise resource planning systems (ERP)[18]. We run two versions of our preferred regressions, one with and one without time trend, to account for potential collinearity issues between GDP per capita and time.

The results for both DBMS and ERP adoption are reported in Table I.15. In this table we estimate adoption regressions for both Europe and the US. Based on data availability, we use a sample from 2000-2007 in Europe and 1996-2007 for the US. We uncover a number of similarities and differences across the two technologies considered. First, there is a strong and significant size effect across both technologies and all specifications. The magnitude of the effect is larger for DBMS, suggesting that it is now only the smaller firms left that have not adopted DBMS yet. The size effect can be due to different underlying reasons. First, larger firms may have more complex operations and therefore need advanced ICT to aid their operations, or the cost savings may apply to a larger total output, resulting in higher profit increases. Both these potential explanations suggest that the benefit from adoption may be higher for larger firms. Second, as we do not have price information in our dataset, larger firms may have a lower cost per worker due to increased bargaining power (the software industry reports significant quantity or size discounts) or because there is a fixed cost of setting up an advanced ICT system, which may result in lower adoption cost per worker (or workplace) for larger firms. Both the benefit-based and the cost-based explanations are likely to result in larger firms having more incentive to adopt.

An interesting difference in the results for DBMS and ERP is in the role of ICT intensity. PC intensity and the percentage of ICT employees in a firm matter for the adoption of Database Management Systems, while only the number of ICT employees is significant in all cases for ERP adoption (this result is robust to leaving out either of the two variables and considering the effect on the other). This suggests differences in who uses each technology. Specifically, DBMS are typically “fed” with data by all employees and accessible to most employees with PC access. This means that the percentage of employees equipped with PCs will play an important role in the adoption of DBMS. Conversely, ERPs are so-called expert systems which are typically set up, used and maintained by experts. This is a tentative explanation of why the percentage of end-user PCs is not found to be significant in the ERP adoption regressions. Our time trend is positive and significant when it is included in our regressions.

The regional spillover effects are always significant in our regressions (Goolsbee & Klenow (2002). This is the case for both Europe (where we use NUTS1 regions) and the US (where we use states as the regional indicator). The coefficient on the spillover terms is larger for the US but the different levels of aggregation between the two samples makes (ie: state versus region) it harder to directly compare the effects. There are various potential reasons for this result: knowledge spillovers (Irwin & Klenow,1994; Jaffe et al.; 1993) may lead to firms in the same region adopting the same software even if they are not operating in the same product market. These spillovers are likely to originate from movements on local labour markets and through the supply of labour skilled in using particular kinds of software. Further, network externalities and

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[18] Note that we cannot use FE because time-invariant dependent variables are dropped which would lead to the loss of all observations that have not changed the adoption status during the observation period.

urbanisation may lead to co-usage of firms located in proximity of each other (see Forman et al., 2005; Gaspar and Glaeser, 1998). A major problem of interpretation, however, is that we are regressing the endogenous variable on a aggregated version of the same endogenous variable, albeit lagged one period. Thus the estimates may simply reflect some unobservable shock such as growing human capital or demand in the region that we are not properly controlling for (see Manski, 1993).

Finally, for results not included in this report, we split the industries in our sample into ICT intensive using and non-intensive ICT-using industries. While we might have expected that a firm in the former industry group is more likely to adopt DBMS and/or ERP, our regressions suggest that this is not the case. This implies that the results we find are not driven by effects occurring in the most ICT-intensive sectors of the European economies.

(iii) Micro-Timing Approach

An alternative to a panel data adoption model is to study the timing of adoption using a hazard rate model. The question asked here is how long a firm "at risk" (i.e. not having adopted a specific technology previously) will take to "fail" (i.e. to adopt the technology eventually). Measuring the length of these spells and identifying determinants of spell length is the focus of this approach. As mentioned above, in the regressions we looked at the usage decisions of all firms in our sample. In this section, we provide a closer look at the firms that had not adopted at the start of our sample in 2000. This means that we can get a more nuanced picture of the "new adopters" of given technologies. In technical terms then, not having adopted at t = 0 (i.e. in 2000) places a firm "at risk" of adopting some time after. By running a regression with the time until adoption takes place as a dependent variable, we can derive the hazard rate of a firm adopting at time *t*. Allowing for this hazard rate to depend both on firm-, industry- or country-specific covariates and let it vary over time, we implement the following Weibull hazard rate specification for firm *i*:

$$h_i(t, X_i) = pt^{p-1}e^{(\beta' X_i)}$$

The X_i corresponds to the regressors of the micro adoption model reported in the previous section, and the sample is also restricted to the manufacturing sector only. The parameter p indicates if the baseline hazard increases ($p>1$) or decreases ($p<1$) over time. Given the positive time trend we found in the micro-adoption approach, we expect $p>1$ in our Weibull regressions. Thus, the hazard rate model above models (exogenous) changes in the propensity to adopt over time and therefore complements the micro-adoption approach by estimating a changing baseline hazard and deriving the corresponding hazard and/or survivor functions.

We report the results for the technologies used in the previous section in Table I.16. In this table we concentrate on manufacturing because this segment of the Harte-Hanks data has good coverage for these types of software. We alternate the inclusion of industry and country dummies between columns and present a more detailed breakdown of ERP-types in panel (B). Our estimates suggest that the propensity to adopt is increasing over time at a decreasing rate with $1 < p < 2$. The only exception is the DBMS regression without dummies included. It is helpful to contrast our results with some of the findings of the micro-adoption estimates. Note that our regressors are specified in the same way in both approaches, and we consider the same technologies as in Table I.11.

Specifically, we find that high penetration in a region decreases the hazard of adopting. This runs counter to the positive effects we find in the adoption regressions, and further makes us suspect that the earlier "spillovers" were not robust. Further, we find that the coefficients from our estimations on Customer Relations Management ERP adoption timing are most similar to the ones found in the micro adoption approach. This is intuitive when considering the penetration rates in 2000 which determine the pool of firms that enter the hazard regressions (previous adopters are not "at risk" any more). Here, ERP CRM has by far the lowest penetration rates, suggesting that almost the entire sample of firms can still adopt. This is reflected statistically in the large number of observations in our regressions, but intuitively it implies that the early part of the diffusion curve that has been truncated in the other regressions appears to be driving these results.

Summary of ICT Adoption

- ICT adoption can be modeled in a number of ways that are suited to different questions. The macro-diffusion approach models an aggregated diffusion process following a logistic curve model. This approach is useful for benchmarking a given empirical diffusion trend. The results here indicate that, among themselves, the European countries share similar inflection points and that the Scandinavian countries have higher penetration ceilings. However, the overall results for the macro-diffusion approach indicate that microeconomic modeling is a more suitable approach.

- Following the micro-adoption approach, we model the determinants of both general PC adoption and software adoption. On PC adoption we find that wages and multinational are positively correlated with PC adoption. Multinational status in particular has an important effect since it is associated with a 10% high rate of PC adoption. In contrast a 10% increase in company wages is only associated with a 1% higher rate of adoption. Cross-country comparisons are dominated by a "digital divide" in PC adoption between Western and Eastern Europe – establishments in the West are characterized by 2 more computers per 10 employees compared to firms in the east. Within Western Europe, the cross-country differences are minimal, with some evidence of a higher PC intensity in the Anglo bloc's financial services industries and the Germanic bloc's wholesale and retail sector.

- Two types of software are considered in adoption regressions, Database Management Systems (DBMS) and Enterprise Resource Planning (ERP) systems. There are positive firm size effects across both technologies but PC intensity is only a significant factor for DBMS software. This is probably due to the fact that DBMS software is directly used across more employees within a firm. The regional penetration indicators are slo significant indicating the presence of spillover effects. These effects could be driven by knowledge spillovers in the usage of technologies (ie: learning from geographically close firms) or network effects that lower the costs of adoption as more firms take up a technology.
- Using a hazard rate approach that estimates the time until adoption, we find that the results on the adoption of Customer Relationship Management ERP systems are similar the ones from the micro-adoption approach, which is intuitive as the low penetration rate in 2000 (the start of our estimations) implies that both estimation methods use the same sample. Interestingly, the adoption processes of all software technologies we study display increasing baseline hazards, implying that adoption of the software will take place eventually in most firms that are "at risk" (i.e. have not adopted yet). That is, we do not expect a separation of firms into "early adopters" and "non-adopters", but rather in "early" and "late" adopters.

C ICT AND REGIONAL CLUSTERS

This Section is concerned with the role that ICT plays in determining economic geography (i.e. the location of economic activity across space). 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. Counter arguments to the "death of distance" are possible, however, as many "weightless" ICT intensive industries appear to be clustered (e.g. Cigan's 2005 analysis of Internet firms in Germany).Thus, we examine the importance of geographical factors in influencing the formation of innovation clusters (that is, concentrations of innovative, high-tech industry). This Section considers these issues by drawing three empirical strategies. The first relates to the use of our AMATECH data to understand the determinants and extent of regional technology disparities. The key question is the degree to which a "digital divide" may exist in the regional distribution of technology and we give an example of this approach using UK AMATECH data. The second strategy involves a specialised analysis of UK data from the Office of National Statistics (ONS). The analysis here looks at how ICT usage may determine spatial concentration, defined following the measures proposed by Ellison and Glaeser (1997). The final strategy looks at impact of distance on knowledge spillovers from patenting. We look specifically at the role of university patents in facilitating localisation in high-tech sectors of the economy.

(i) Analysing the "digital divide"

The first interim report canvassed various contributions relating to the "digital divide" in the distribution of ICT (e.g.: Norris 2001; Cigan 2005; Chinn and Fairlie 2004; Townsend and Moss 2000). A key empirical issues here it the extent to which differences in technology usage persist even after controlling for firm characteristics as well as other regional characteristics such as skills or R&D. Therefore following the discussion of ICT uptake in section I.B it is useful to explicitly consider these regional differentials as part of a simple adoption equation.

In Table I.17 we investigate the evidence for any regional "digital divide" in ICT adoption in the Europe using the establishment-level Harte-Hanks data. The digital divide can be defined across two dimensions. Firstly, there is the difference in technological adoption that can be explained by observable region characteristics, particularly industrial composition. Secondly, there is the difference left over after the inclusion of observables. This residual difference is arguably the persistent component of regional differences and reflects gaps that are due to so far unobservable factors. In Table I.17 our dependent variable is PC intensity and we focus on the UK, France and Germany since these countries have the biggest samples for looking at regional differences. The regions are defined at the NUTS1 level and there is a common three column sequence across the tables. In the first column we present the "raw" differences in PC intensity controlling only for establishment type (ie: HQ, Branch, Semi-Branch) and establishment size (log employment). In the next column we add controls for two regional characteristics, R&D spending and levels of secondary and tertiary education. The final column then includes a full set of SIC4 industry fixed effects. Hence each step controls for additional factors that can explain regional differences in technological adoption. The results show a consistent pattern across countries – the inclusion of regional characteristics eliminates around 20-40% of the regional differences in many cases and the inclusion of industry fixed effects eliminates around 50-70% of the gap in total. Therefore in policy terms, this table shows how much of the digital divide is within the reach of policy-makers. That is, a certain fraction of the differences can be addressed by improving education levels and infrastructure while those differences due to industrial composition are much harder to shift.

(ii) The Importance of ICT for Spatial Concentration

This sub-section is concerned with the role that ICT plays in determining economic geography (i.e. the location of economic activity across space). Economic activity tends to concentrate geographically because it is costly to transport goods, people and ideas across space. Historically, new technologies – the steam engine, railways, and the combustion engine – have reduced the costs of shipping goods and people across space. The telegram, telephone and, more recently, new ICT have also reduced the costs of exchanging information, images, data, etc over both short and long distances. In business and policy circles, the commonly held view is that the recent rapid advances in ICT will *lower* transaction costs sufficiently that we should see the spreading of economic activity more evenly across space. This section considers this argument drawing on contemporary research in economic geography.

We argue that contrary to the prominent claims of a "death of distance", economic theory remains ambiguous about the effect of ICT on geographic concentration. Transaction costs mean that physical proximity provides benefits thus giving incentives for organisations and individuals to concentrate in space. 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 scarce 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. But because changing transaction costs affect *both* forces the impact on economic geography is ambiguous.

The fact that theoretical predications are ambiguous increases the importance of systematic empirical evidence if we want to understand the impact of ICT on economic geography. Unfortunately, while anecdotes abound, relatively little systematic evidence is available. From a policy perspective, this lack of evidence is troubling, because it is clear that ICT will partly determine the evolution of urban and regional disparities. In the absence of hard evidence to the contrary it has often been assumed that ICT will lead to dispersion and can thus be used as a tool for helping address current disparities (as reflected, for example, in the EU's i2010 and Lisbon Strategy). In this section of the report, we consider this issue, by focusing on the role that ICT plays in determining the *geographical clustering* of particular sectors. We provide evidence for the UK that ICT may help increase the dispersion of manufacturing sectors but it appears to have little impact on the overall location patterns of service sectors. Given the ongoing shift towards service activities across the EU this raises questions about the extent to which ICT can be viewed as a natural complement to policy efforts to reduce regional disparities.

The rest of this section is structured as follows. We begin by briefly considering the theoretical and empirical evidence on the impact of ICT on economic geography. We then outline our methodology, data and findings before offering some conclusions.

Existing Literature and Theoretical Background

Amongst economists there has been a recent resurgence in interest in economic geography, partly reflecting the influence of Nobel Prize winner Paul Krugman's work in the area. We do not attempt to provide a systematic review of this rapidly expanding literature. Instead, we focus on work that has examined the specific issue of the impact of ICT. The interested reader is referred to Baldwin, Forslid, Martin, Ottavianno and Robert Nicoud (2003) and Combes, Mayer and Thisse (2009) for broader overviews.

As discussed in the introduction, changes in transaction costs as the result of improvements in ICT will change the balance between agglomeration and dispersion forces and thus 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, 2007). 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, as discussed above, falling transaction costs affect both agglomeration and dispersion forces and the overall effect is thus ambiguous. 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 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 if it is ICT that drives the reduction in 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 effects are 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 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 emphasise 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 quick 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.

Empirical Evidence

When it comes to the real world impact of ICT on spatial concentration, there is a large amount of case study evidence but 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 (2006) provide an international example using data for a sample of more than 160 countries. Townsend and Moss (2000) are an early example studying 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 coauthorship. 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 and 1997.

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 (2000) 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 correlation between city size and internet density, while a complementary relationship should result in a positive correlation. In line with the results on telephony, Kolko finds evidence in support of a positive correlation.

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 emphasise 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 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.

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. We now turn to our own research and provide some evidence that the effect on individual industries may be consistent with this overall pattern.

Empirical Methodology

We want to examine whether industry ICT usage increases or decreases geographic concentration of that industry. To do this, we construct a measure of geographic concentration for each sector and regress it on a measure of the ICT usage in each sector. Of course, other characteristics of industries may also affect the extent of concentration, and we will need to control for these. To do this, we estimate:

$$S_j = \beta_1 ICT_j + \beta_2 X_j + e_j$$

where S_j is a measure of geographic concentration for sector j, ICT_j is a measure of the ICT usage in the sector, X_j is a vector of sector characteristics that might also influence the degree of geographic concentration, e_j is an error term and the betas are coefficients to be estimated.

This approach to investigating the significance of different motives for geographic concentration has been used before (see Audretsch and Feldman, 1996, and in particular Rosenthal and Strange, 2001, to which our regressions are most directly related). The novelty of our analysis is to include measures of ICT usage, an issue which has previously been ignored in the literature.

There are a variety of statistics that can be used to measure the extent of geographic concentration. We adopt the widely used index proposed by Ellison and Glaeser (1997). This measures the amount of geographic concentration in a sector over and above that which we would expect to find based on randomness alone. It has the advantage of being comparable across sectors and controls for both the overall geographic concentration of employment and for the “lumpiness” of employment. This lumpiness arises because industrial concentration means plants are of different sizes. This is a problem when trying to measure geographic concentration, because even random distributions of plants across space can give rise to some places having more employment than others (if they happen, by chance, to get a particularly large plant). Because the Ellison-Glaeser index controls for industrial concentration of the industry it corrects for this problem.

One obvious concern is that ICT usage may be driven by location patterns rather than vice-versa. To allow for this, we will instrument our measure of ICT usage using the ICT usage for comparable sectors in the US. We expect ICT usage in a sector in the US to be correlated with ICT usage in the same sector in the UK. But there is no reason to think that ICT usage in a sector in the US should be affected by UK economic geography. ICT usage in the same sector in the US should, therefore, provide a suitable instrument to help deal with the problem of endogeneity. As discussed above the theoretical literature is ambiguous about whether we should find a positive or a negative effect of ICT usage on geographic concentration.

Data

Our research focuses on the UK where we have access to the data necessary to calculate the Ellison and Glaeser index. This is calculated using exhaustive establishment level data from the Annual Respondent Database (ARD) which underlies the Annual Census of Production in the United Kingdom. We use data from 1997–2006. The data set is collected by the Office for National Statistics (ONS) and covers all UK establishments. For every establishment, we know its postcode, four-digit industrial classification, and employment. The data covers both manufacturing and services. Given sample sizes, we construct the Ellison and Glaeser measure for 3 digit SIC sectors. As spatial patterns only change slowly we help reduce measurement error by averaging across the years 1997 to 2001 and 2002 to 2006 to give us data for two time periods that we refer to as periods 1 and 2.

To measure ICT usage we use computers per employee from the entire UK Harte-Hanks sample of establishments from 1998 onwards. Our instrument is constructed using the same variable taken from the US Harte-Hanks sample also from 1998 onwards. We average both across time using the same time periods as for the Ellison and Glaeser measures.

Our controls for other industry characteristics come mainly from the ONS Input-Output tables, available annually from 1994 to 2004. We complement these where necessary with Eurostat’s Detailed Enterprise Statistics for the United Kingdom and the ARD itself. Industry skill intensity comes from the LFS. We provide more details below. Given the shorter time period for the IO tables and larger underlying samples we just use values from years 1997 and 2002 rather than time averaging these variables as we do for the EG and ICT measures.

We consider a range of additional controls. We briefly consider each in turn. The control variables broadly follow Rosenthal and Strange (2001). We briefly motivate all of them, but refer the reader to Rosenthal and Strange (2001) for a more detailed discussion.

As emphasised in models of new economic geography, the level of transport costs for an industry will be crucial in determining whether agglomeration forces outweigh dispersion forces leading to the geographical clustering of the industry. We use transport services (IO93–97) as a share of inputs to capture the impact of transport costs on industry geographic concentration, using data from the ONS Input-Output tables. As Rosenthal and Strange (2001) argue, this measure is not ideal as it is most likely endogenous. Unfortunately, for the UK, alternative data are not available in the time period that we consider.

We use the purchase of goods and services as a share of inputs to capture the importance of vertical linkages. These are calculated using the input coefficients on manufacturing (IO8–84) and nonmanufacturing industries (IO107–115, 118–123), respectively, from the ONS Input-Output tables. The basic idea is that industries who buy or sell a lot from other plants may have an incentive to cluster near those plants. If the degree to which an industry buys goods and services as inputs captures this effect, then we should expect the coefficient on these two variables to be positive.

As discussed in Overman and Puga (2009), although share of inputs is widely used in existing literature the variable can be hard to interpret. When an industry buys a lot from other industries, the effect on its concentration should depend, in turn, on whether those industries are spatially concentrated or dispersed. As Overman and Puga (2009) note “The meat processing industry is a large buyer of inputs from farms and from the plastic film industry. However, farms are very dispersed across the country and so is the plastic film industry, since it supplies many other sectors located in different places in addition to meat processing. Hence, the meat processing industry has no reason to concentrate spatially even if it makes large intermediate purchases: it can easily find its inputs everywhere”. Thus, to better capture the importance of vertical linkages we follow the suggestion of Overman and Puga (2009) and calculate the input share weighted sum of the Ellison and Glaeser index across all industries from which an industry purchases intermediates. For obvious reasons we exclude own industry and, instead, capture the effect of purchases from own industry on concentration by including the share of purchases that come from own industry as a separate variable.

Finally, we allow for the fact that skilled workers are unequally distributed across places and that industries differ in the intensity with which they use skilled workers. Given that skilled workers are concentrated we might expect industries that use skilled workers intensively also to be concentrated. As industry skill intensity may well be correlated with ICT it is important to control for this possibility. We do this using a measure of skill intensity constructed from the UK Labour Force Survey (LFS) focusing on the proportion of degree-educated workers in each relevant industry cell.

In preliminary work, we also considered the possibility that the use of natural resources, water or energy may have an effect on concentration (using data on shares of primary inputs, water inputs (IO87) and value of energy purchases, respectively). None of these variables were significant and their inclusion did not affect coefficients on variables of more interest, so we do not consider them further in the results we discuss below.

Results of Analysis

We now turn to our results. We begin by plotting our measure of geographical concentration in period 2 (2002-2006) against the ICT usage of industries. Figure 1 shows that, for manufacturing, higher ICT usage is associated with lower geographical concentration. In contrast figure 2 shows that, for services, higher ICT usage tends to be associated with *higher* geographical concentration. These correlations remain even when we remove the obvious outliers. Results reported in Table I.18 confirm the sign of these correlations and that both are significant. Columns 1 and 2 of Table 1.18 show the results for manufacturing and services from regressing geographical concentration against ICT in the first period, while columns 5 and 6 report the same results from the second period. Columns 3 and 4 and columns 7 and 8 show what happens when we introduce the other characteristics of industries, discussed above, that might be correlated with both ICT and geographical concentration. For manufacturing we see that, in both periods, the negative association between ICT and geographical concentration is robust to including these additional industry characteristics. The coefficients on the individual characteristics are insignificant but, as can be seen from the increase in R-squared, they do jointly play a role in explaining the concentration of industries.[19] For services, we see that the positive correlation between ICT and geographic concentration does not persist once we include additional controls. In the first period, it appears that vertical linkages play a role in explaining away this association. By the second period it seems that skills have become a more important explanation of geographical concentration for services. Regardless, once we control for these other characteristics of industry we find no association between ICT and geographical concentration for service activities.

At this point we cannot rule out the possibility that the association (or lack of it) between geographic concentration and ICT is actually driven by firms making their location decisions and then deciding on their ICT usage. For example, the negative correlation between concentration and ICT usage for manufacturing could be explained by the fact that more dispersed industries happen to use more ICT to communicate with customers and suppliers. In the absence of ICT these industries could still be dispersed and use, say, personal visits or telephone calls to communicate with customers and suppliers. Given that we are predominantly interested in the impact of ICT on location (not vice versa) we would like to rule out the possibility that this kind of reverse causation explains our results. One way to do this is to find a suitable instrument for ICT usage. A suitable instrument should be correlated with ICT usage but independent of the location of the industry. As suggested above, we use US ICT usage. US ICT usage likely provides a suitable instrument because, while ICT usage in US industries is likely to be correlated with ICT usage in UK industries, it is hard to see why the location pattern of a UK industry should affect the ICT usage of a US industry. We report first stage regressions in Table A1 of the appendix that show that US ICT usage is, indeed, strongly partially correlated with UK ICT usage.

Table I.19 reports results when we use US ICT to instrument for UK ICT. We see that across all specifications the coefficient on ICT is unchanged. For manufacturing, in both periods, there is a negative correlation between geographical concentration and ICT usage. For services, the association is positive when we do not control for other characteristics of the industry but insignificant once we do.

Next, we use the fact that we have two time periods to consider the possibility that unobserved characteristics of industries that are correlated with both industry-level ICT and geographical concentration may be driving our results. To do this, we estimate the empirical model using industry fixed effects. We report results in two parts. The first panel of Table I.20 shows what happens when we ignore the possibility that ICT usage is endogenous. That is, we report the standard fixed effects estimates. The second panel of Table I.20 shows what happens when we allow ICT to be endogenous and instrument using US ICT. From the first panel we see that, once we allow for unobserved characteristics of industries it is important to control for observable characteristics to detect a negative association between manufacturing and ICT. As before, we simply find no evidence of an association between geographical concentration and ICT usage for services. The second panel shows that, once we allow for the possibility that UK ICT is endogenous we find no association between ICT and geographical concentration for either manufacturing or services. As the first stage regressions reported in Table A2 in the appendix make clear, the problem with interpreting these results is that while US ICT remains a reasonable instrument for UK ICT for service industries even once we include industry fixed effects, the same is no longer true for manufacturing.

Summary of Spatial Concentration and ICT

- Theoretically, the effect of ICT on spatial concentration is ambiguous. ICT can affect spatial concentration on two margins, either in terms of facilitating the dispersion of economic activity (by lowering transaction and communication costs) or by encouraging

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[19] This finding of joint significance but individual insignificance is quite common in the literature. See Rosenthal and Strange (2004) for further discussion.

agglomeration. The latter effect is a result of the ambiguous effects of falling transaction costs. Models indicate that falling transaction costs can increase tendencies to concentration through increasing returns to scale and by encouraging the demand the demand for managerial services in production that do still rely on physical proximity.

- The existing empirical evidence on ICT and spatial concentration suggest that while ICT may be facilitating the spreading out of overall activity across cities there is also a tendency for particular firm and industry functions to increase their level of concentration in the overall spatial distribution. This latter concentration effect is consistent with the arguments made in the theoretical literature.

- In our empirical work we construct a measure of spatial concentration using UK Business Census data and relate it to measure of ICT usage. The basic analysis indicates a negative relationship between ICT and spatial concentration for manufacturing and a positive relationship for services. While the result for manufacturing is robust to the inclusion of industry controls the relationship between ICT and spatial concentration fades out when these controls are added.

- Endogeniety concerns may still affect the result for manufacturing since firms may make their location choice before making decisions regarding ICT usage. To deal with this possibility we use US industry ICT usage as an instrumental variable (IV) since this should be orthogonal to UK spatial concentration patterns. The negative relationship between ICT and spatial concentration is also evident in this IV specification although the relationship is statistically weakened when industry fixed effects are also included.

(iii) Knowledge Spillovers, Universities and Localisation

The location and productivity of high-tech research clusters has been a major focus of policy attention since the rise of Silicon Valley in the 1980s. Moreover, following a range of famous international examples[20] there is an increasing enthusiasm among policy-makers on the role that science-based research clusters (particularly those linked to universities) might play in this connection. We focus on the US because this is where the data is most developed and available, but we believe the lessons from this data can be generalised to the European experience.

This interest is based, at least in part, on the assumption that knowledge spillovers are strongly influenced by geography - in particular, that they have a strong localised character that can best be exploited by an agglomeration of high technology activity. If knowledge spillovers were not heavily localised, the justification for concentrating research-based firms would be much weaker. Therefore, it is very important to understand clearly how geography shapes knowledge spillovers, and how the institutional characteristics and policies of the research institutions, around which clusters form, influence this dissemination of knowledge.

In this sub-section we study these issues in the context of university knowledge spillovers in the US. We utilise newly constructed datasets on patents, patent citations and university characteristics. This information includes the actual distance between citing and cited (university) patents, based on the location of the inventor listed on the patent. We focus on three main questions. First, what is the geographic profile of knowledge spillovers from *university inventions*? In this we study both the sensitivity of spillovers to distance, and the role of state boundaries in constraining such diffusion. Second, do technology fields differ in the localisation of spillovers? Are newer fields like biotechnology and, in particular, information technology different from more established high-tech areas like pharmaceuticals, mechanical and electronic technologies? These questions are highly relevant to the public policy issue of

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[20] In addition to Stanford's influence on Silicon Valley these include (most notably) the experience of Cambridge UK and Boston's Route 128.

how much emphasis to place on promoting high tech clusters around research universities. The estimation approach that we will use follows that established in the literature on patent citations (e.g.: Jaffe, Trajtenberg and Henderson 1993; Thompson 2006) which use the cell-based probability of citation as a dependent variables regressed on standard controls and distance metrics. Finally, a new feature of our analysis will be improved distance metrics directly sourced from Google Maps.

In the following we present the econometric analysis of citation probabilities. The descriptive statistics and background of the data can be found in Appendix as Tables A3 and A4. Table I.21 presents the basic econometric results relating citation probability to geographic distance and state borders. In all regressions, we include university and state fixed effects, the grant years for the cited and citing patents, dummy variables for pairs of five high-technology clusters, and a dummy variable for whether the citing and cited patents are in the same 4-digit patent class.[21] The coefficients reported in the table are the estimated marginal effects from Probit regressions. We begin with the simplest specification that relates the citation probability to a continuous distance measure (log of miles). In column (1) we find that distance has a statistically significant but small impact in dampening citations. A ten percent increase in distance – which corresponds to 120 miles, if evaluated at the sample mean -- is associated with a 0.45 percentage point increase in the probability of citation. This is equivalent to only a 1.9 percent increase relative to the mean citation probability.[22] It is also worth noting that the coefficient on the technology matching dummy is large and statistically significant, confirming the findings of earlier researchers that citation is much more likely between patents in the same technology areas. This conclusion is robust across all specifications we estimate.

In column (2) we replace the distance measure by a within-state dummy. The estimated parameter shows that citation is much more likely from inventors located within the same state – the marginal effect of being within-state is very large – 0.225, which is nearly half the size of the mean citation probability. Column (3) reports results for the specification that includes both the distance measure and the within-state dummy. The results confirm that both distance and the state border effect are statistically significant, and that it is important to both variables. Including distance reduces the estimated effect of the state border from by more than 50 percent, from 0.225 to 0.104. At the same time, including the within-state dummy also reduces the estimated impact of distance by half, from -0.045 to -0.024.

There is the further concern that part of the reason there appears to be a state border effect is that we have not allowed for non-linear distance effects. To address this, in column (4) we introduce a set of dummy variables for different distance intervals. Two key findings emerge. First, the estimated state border effect is robust to allowing for flexible distance specification. The estimated marginal effect of crossing the state border is 0.097 – this represents about 20 percent of the mean citation probability, and is very similar to the estimate of 0.104 obtained with the more restrictive distance formulation. This result confirms that the border effect is not simply a proxy for geographic distance. The second important result in column (4) is that geographic distance sharply constrains knowledge spillovers – moving from 0-25 to 25-50 miles reduces the citation probability by 22 percentage points, and moving out to 50-100 miles further

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[21] Including university and state fixed effects in the Probit regressions does not cause classic 'incidental parameters' problem (and the associated parameter bias) because the limiting dimension for consistency here is the number of patent citations, not the number of universities or states.

[22] Our estimate of the distance effect is larger than that obtained by Peri (2005), who estimates that an increase in distance of 1000 km (600 miles) is associated with a reduction in citations of about 3 percent. Evaluated at the sample mean distance and citation probability, our estimate implies that an increase of 600 miles would be associated with a 9.5 percent decline. Part of this difference disappears when we include a state border effect (column (3)). But our finding of greater localisation may also be due in part to our focus on university patents. In the next phase of this research, we plan to investigate the comparative localisation of university and firm-owned patents. Adams (2002) is the only such study of which are aware, and he finds that university patents are more localised than others.

reduces it by another 30.5 percentage point. But after that, distance has no appreciable effect on citation[23].

One concern is that the geographic profile of knowledge diffusion may be very different for patents that represent significant technological and/or economic advances, as compared to more marginal improvements. In particular, we might expect important ideas to diffuse more widely.[24] While we have no direct measure of the technological step made in a patent or its economic value, we investigate this hypothesis indirectly by using the total number of citations that a patent receives (over its lifetime) as a proxy for its importance.[25] In column (5) we re-estimate the regression for patents whose number of total citations received is below the median; column (6) is for university patents with citation counts above the median. The coefficients on the distance dummies confirm that 'low-value' patents exhibit greater localisation – their knowledge spillovers are more constrained by geography than those from high-value patents. Moving from 0-25 to 25-50 miles reduces the citation probability by 50 percent more for low-value patents than for high-value ones (-0.290 versus -0.202), and by about 35 percent more as we move to a 50-100 mile radius (-0.391 versus -0.286). But it also interesting that for both categories of patents, the distance effect is essentially exhausted after 100 miles.

We turn next to a set of regressions that investigates how university and state policy variables affect the impact of state borders on knowledge diffusion. The results are given in Table I.22. We begin by examining the impact of university ownership. Columns (1) and (2) present the baseline specification separately for private and public universities. The results point to a striking difference: public universities generate more localised knowledge spillovers than private universities. Two separate results support this conclusion. First, patent citations decline more sharply with distance for public universities up to 100 miles, as shown by the coefficients on the first two distance dummies. Moving from 0-25 to 25-50 miles reduces the citation probability by -0.287 for public universities but only -0.204 for private ones. Moving further out to 50-100 miles is associated with an additional reduction of -0.367 for public and -0.289 for private universities. However, we again find that the effects of distance die out after 100 miles, and this holds both for public and private institutions. Second, the effect of the state border on citation is stronger for public universities – being within-state increases the citation probability by 0.114 for public and 0.076 for private institutions. But even for private universities, the border effect is quite large – representing about 15 percent of the mean citation probability.[26]

In column (3) of Table I.22 we estimate the baseline specification with the pooled sample of both public and private universities, but allowing the coefficients on all of the distance dummies and the state border dummy to be different for the two types of universities (i.e. we interact the dummy variable for private ownership with both the distance and within-state dummy variables).

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[23] We can test the hypothesis that there is no incremental distance effect beyond 100 miles by constraining the coefficients on those dummy variables to be the same as the coefficient for the 50-100 mile dummy. We do not reject this hypothesis if we exclude the last dummy, which captures mostly bi-coastal effects (greater than 1000 miles) – the p-value of the test is 0.73 (χ^2 test statistic of 2.05).

[24] In addition, important ideas might spread more rapidly. The linear effect of citation lag is already controlled for in the construction of the control group of patents (because we match the control and citing patents on application date). However, we could examine whether the effect of citation lag differs for low and high value patents by including an interaction term between citation lag (equivalently, the date of the citing patent) and a dummy variable for patents which have citations above the median.

[25] There is a large empirical literature showing that such citation measures are correlated with various measures of economic value, beginning with the classic studies by Trajtenberg (1990a, 1991b). We observe patents granted up to 2006 and citations through the year 2007, so there is an issue of truncation for the more recent patents. However, since we study the relationship between citation and distance, and not the number of citations *per se*, truncation would only cause a problem to the extent that the timing of citations is correlated with distance (e.g. earlier citations to a patent are from less distant inventors). Since that is possible, we checked robustness of results by re-estimating the specification in column (4) in Table 3, using only patents granted before 2000. The results are very similar to those in the table. For example, the coefficient on the within-state dummy is 0.096, which is nearly identical to the one from the full sample in column (4).

[26] These differences between public and private universities are not due to patent quality differences. We still find the differences between public and private universities in the distance and state border effects when we estimate the specification on low value (below median citation) and high value patents, separately (not reported, for brevity).

In addition, we include an interaction between the state border effect and a measure of the high-tech density of the university location (TechPole). We do this in part because leading private universities are located in very high-tech areas, such as Boston, Silicon Valley and Raleigh-Durham. Thus there is a concern that the difference between the state border effect for private and public universities may overstate the real impact of university ownership status. However, the results in column (3) confirm the earlier conclusion that the state border effect is more important for public universities than for private ones – the estimates are 0.184 and 0.095, respectively. The new finding is that the state border effect is less important for universities that are located in more high-tech areas. Having greater local (high-tech) demand for inventions appears to reduce the impact of state borders on citation. To illustrate the quantitative implications, the point estimate implies that moving a university from Iowa City to Chicago would be associated with a 2.2 percentage points [-0.006 x (3.75-0.063)]; moving it to Boston would reduce it by a further 1.5 percentage points [-0.006 x (6.31-3.75)]. Compared to the baseline estimates of the state border effects, these impacts are not small.

The evidence shows clearly that state borders constrain knowledge diffusion more for public universities than for private ones. But why should this be so? Is it something intrinsic to ownership, or is it associated with university characteristics and policies that are themselves correlated with ownership status? To examine this key question, in column (4) we add to the specification interaction terms based on four university and state policy variables: local/regional development objectives of the university, the severity of state government constraints on university technology transfer activity, the use of performance-based pay by technology transfer offices, and whether the university is a land grant institution. The results are quite striking: we find that the state border effect is more important when universities have strong local development objectives, and when they are more constrained by state government regulations. For public universities that have strong local development objectives, the state border effect is 0.174; for public universities that place little weight on this objective, the border effect is reduced by about a quarter, to 0.134. For private universities, the corresponding state border effects are 0.127 and 0.083. We also estimate that each “effective” state constraint increases the state border effect by 0.018. At the sample mean (three constraints), this implies that state regulatory constraints on university technology transfer increase the impact of state borders on citation by 0.054, which about a third of the baseline estimate of the border effect for public universities.

These two findings together suggest that university and state policies regarding technology transfer can have a significant effect on the pattern of knowledge diffusion, and thus economic growth. Moreover, taking into account these policy variables dramatically reduces the estimated impact of private ownership. The coefficient on the interaction between the private ownership and state border dummies declines by about half, from -0.089 in column (4) to -0.047 in column (5), but the smaller coefficient is still statistically and economically significant (it implies that the border effect is about 30 percent smaller than for public ones). This result shows that private ownership is still associated with wider (less localised) knowledge spillovers, even after we take into account certain university and state policies that happen to be correlated with ownership status. Our conjecture is that this residual role is not due to something intrinsic to private ownership, but rather to other policies that we have not accounted for. But that question remains for future research.

Column (4) also shows that the use of incentive pay by the university technology transfer office does not have any statistically significant impact on the localisation of knowledge spillovers – even though the estimated coefficient on the interaction between the state border and incentive pay dummies is negative, as expected. Belenzon and Schankerman (2009) show that bonus pay substantially increases license revenues earned from university inventions. Since the appropriate licensee may not be within the state, high powered incentives make it more likely that the invention is licensed elsewhere (other things equal). If licensing facilitates knowledge diffusion, one would expect to find that the state boundary effect is smaller for universities using such incentives. The results do not support this hypothesis using the full sample. We also find no effect of the land grant status of the university.

Finally, in the last two columns in Table I.22 we examine whether the geographic profile of knowledge spillovers, and the role of policy variables in shaping that profile, changed over time. To do this, we re-estimate the specification in column (4) for two sub-periods: 1976-1993 and 1994-2006 (1993 represents the median year for citations in the sample). The breakdown by period is based on the date of the cited patent, i.e. the 'vintage' of the technology, not the date at which the citation occurs. [27] Overall, the results for the two sub-periods are broadly similar, though some noteworthy differences emerge. The most important finding is that there no evidence of any decline in the localisation of university knowledge spillovers for *later technologies*. In fact, a comparison of the coefficients on the distance dummies shows that localisation is actually stronger for the later period. For example, as we move from the 0-25 to a 25-50 mile radius, the sample citation probability drops by -0.193 for patents from the first period and -0.249 for the second period. Moving to 50-100 miles, the corresponding incremental declines in citation rates are -0.306 and -0.358. In both cases, the localisation is higher and the differences are statistically significant. At the same time, we find that in both periods the constraining effects of distance are essentially exhausted after 100 miles. In addition, the estimated impact of state borders is very similar in the two periods -- the baseline estimates are 0.179 and 0.157, which are not statistically different from each other.

Differences between the estimates of the two periods are evident when we examine the interaction of the three 'policy' variables with the state border effect. While the results are qualitatively similar, we get stronger, and more precisely estimated, effects in the later period (and they are larger than the pooled estimates in column (4)). The coefficient on the interaction between state constraints and the state border dummy is not statistically significant in the first period, but it is 0.028 and highly significant for the second period. This is also true for the impact of (weak) local development objectives on the border effect – the estimated coefficients are -0.027 for the early period, and -0.071 for the later period. The estimated parameter for performance-based pay is also larger, and marginally significant (10 percent level) in the second period. One explanation for the better results in the second period has to do with the timing of when the policies were introduced. Ideally, we would like to study how exogenous changes in these policies affect the importance of state borders, but we have no information on when universities (or states) adopted these policies. We only know what these policies were at the date of our survey of technology licensing offices (2001). If these policies were not in place for the entire sample period, the resulting 'measurement error' in these variables would make it harder to pin down their impact when we use the earlier, 1976-93, period. This is in fact what we find.

All of the preceding analysis was based on pooling the data for different technology areas. We turn next to an examination of whether the pattern of localised knowledge spillovers varies across technology fields. Table I.23 presents the baseline specification estimated for nine broad technology fields, as defined by the patent class of the *cited* patent. These areas are: Biotechnology, Pharmaceuticals, Chemicals, Medical Instruments, Information Technology, Electronics, Mechanical/Engineering, Physics/Instruments and Metallurgy.[28] The results show substantial differences across fields in the degree to which knowledge diffusion is localised. There are two main results worth noting. First, while distance significantly constrains knowledge spillovers in all technology fields, it is distinctly less severe in the Information Technology field. The coefficients on the distance dummies for the 25-50 and 50-100 mile intervals are about half as large for patents in Information Technology as they are in other fields. One possible explanation is that knowledge may be less tacit in information technology, including software which is literally codified, than in the other fields. Information that is more codified is more easily

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[27] It is a separate question whether distance is less important for *later citations*, regardless of what vintage technology is being cited. To study this, however, it is important to control for the interaction of citation lag and distance. We leave this for the next phase of the research.

[28] The international patent classes (IPC) included in each technology field are given in the appendix.

transferred and absorbed without extensive personal interaction that distance may constrain. But it is worth noting, too, that in all of the nine technology fields, the localisation effect of distance largely dies out after 100 (or in some cases, 150) miles. Second, we find a statistically and economically significant state border effect in eight of the nine technology fields (the exception being Metallurgy), but the importance of state borders varies across fields. In particular, we find that the state border effect on knowledge diffusion is much larger in Biotechnology, Pharmaceuticals and Chemicals. Finally, it is noticeable that the private university advantage in the spread of knowledge is not significant for the ICT sector.

Summary of Knowledge Spillovers, Universities and Localisation

- Localised clusters of high-technology production have been a major focus of debates on the knowledge economy and policies towards ICT. In particular, policy-makers are interested in the mechanisms that could foster clusters of high-tech, high-productivity knowledge-producing industries.
- We therefore focus on the role of distance in influencing localized knowledge spillovers. This emphasis on knowledge spillovers is important because it is seen as one of the main determinants of agglomeration. Our specific focus here is the role of universities because they are regularly identified as potential policy vehicles for localized knowledge spillovers.
- We test the effect of distance on knowledge diffusion (measured as citation probabilities) in a number of ways. Firstly, using standard distance measures we find that a 10% increase in distance (equivalent to 120 miles) increases the citation probability by 0.45% and this effect is higher between technologically similar patents. Secondly, there is a larger distance effect in terms of within-state spillovers – this effect constitutes half of the mean citation probability. Finally, public universities are associated with stronger, localized knowledge spillovers that are reinforced by the state border effects.
- With respect to technology fields, the ICT field displays less localization than all other fields. Specifically, the distance effect for ICT patents is around half as large as that for all other technology fields. This indicates that there is probably less scope for policy to induce knowledge spillovers in the ICT-producing area of research.

D ICT AND THE PUBLIC SECTOR

In developed countries, public sector spending in ICT accounts for about 1-1.5% of GDP. This extraordinary investment effort is justified by the growing importance that new technologies play in the management of key government competencies, such as tax systems and welfare benefits. It has also been argued that a sustained public sector push in ICT might increase take-up in the private sector. For example, forcing businesses to compile their tax returns online might represent an incentive to upgrade their ICT systems. However, the implementation of ICT within the public sector might also pose specific challenges. In this Section we discuss some of the key issues that might hinder the successful implementation of ICT investments within public sector environments, as well as the mechanisms through which public sector investments in ICT might affect take up in the private sector.

(i) ICT and the Efficiency of the Public Sector

One of the central themes of this report is that the successful exploitation of ICT requires the presence of a wide range of organisational and managerial practices (see Section II.D for a detailed discussion). This argument is especially compelling for ICT deployment within public sector environments. Dunleavy et al (2006) highlight four main challenges which might inhibit the efficiency impact of ICT in the public sector:

- *Organisational Inflexibility*
  The sheer dimension and complexity of the public sector is, by itself, a major obstacle to the successful implementation of ICT, which, as discussed in Section II.D, requires significant organisational and managerial changes. These problems are exacerbated by the fact that public institutions might be more reluctant to reduce the operating core by cutting clerical jobs, which can easily replaced by technologies. An additional problem in this respect is the fact that the high adjustment costs inherent with ICT deployment have typically inhibited the introduction of piecemeal, cumulative changes across the public sector, favouring instead widely spaced and expensive ICT renewals (the "big-bang cycle" approach). This has often resulted in a tendency in certain governmental environments to adopt expensive systems, which were not inherently compatible with the organisational characteristics of public sector establishments.

- *Technical inflexibility due to full outsourcing*
  Several governments, to different degrees, started from the 1980s onwards to fully contract out the implementation of ICT systems. This reflected a pattern started in the private sector to increase efficiency by concentrating firm activity on core competencies. The trend towards ICT outsourcing was further reinforced in the public sector by the introduction of New Public Management theories (NPM), which emphasised the role for market orientation to achieve greater cost-efficiency in the government. While reducing costs, this pattern however introduced an additional layer of technical inflexibility to the already rigid organisational features discussed above, making it extremely hard to adjust the systems according to the changing needs of the different departments.

- *Lack of in-house specialised ICT skills*
  In the 1960s and 1970s public sector ICT was synonymous with defence and high tech applications. As such, most governments could attract and retain highly skilled individuals to fill ICT related jobs, and thus maintain and innovate internal processing systems. By the 1980s, however, private firms and ICT system companies had gradually overtaken governments in terms of innovation, and were less constrained in setting the remunerations for ICT specialists. This implied an endemic lack of skilled ICT specialists within the public domain which, together with the full outsourcing of ICT systems detailed above, significantly increased the costs of adapting new systems to the specific characteristics of public organisations.

- *Lack of competition in the ICT supply market*
  Finally, Dunleavy et al. emphasise the role played by lack of competition between ICT suppliers for public organisations. This is imputed due to the growth of very large and long-term outsourcing contracts, which was in some countries coupled with the creation of de facto monopolies in ICT supply for public organisations. The lack of competition in this market, it is argued, generated distortions in the quality or quantity of ICT supplied to the government, which in turn significantly reduced the effectiveness of ICT within public sector environments.

The arguments developed by Dunleavy et al. provide a useful conceptual framework to study the role of ICT in the public sector. As mentioned above, however, studying the empirical relevance of these issues with robust statistical methods is hindered by the absence of comprehensive micro level information on public sector outputs, organisational and managerial practices and skill composition. In what follows we will focus on two specific studies, which have been able to overcome these constraints and provide a convincing analysis of the role played by ICT within specific public sector industries, namely police departments and schools.

The first study is by Garicano and Heaton (2009), who look at the impact of ICT adoption across US police departments. The analysis focuses on the changes induced by the adoption of a wide range of Information Technologies (PCs, mobile data terminals, mainframes and servers) between 1987 and 2003. One of the basic findings of this research is that ICT is complementary with skill upgrading even within public sector organisations. Furthermore, while ICT in its own is not associated with substantial increases in the productivity of police departments (measured by clearance rates and crime rates), the analysis suggest that the effects on productivity increase substantially when ICT is adopted together with complementary organisational practices. This study is noteworthy for multiple reasons. First, the analysis is based on an extremely rich micro data set on ICT adoption covering a large sample of US police departments (approximately 8,600) observed over 16 years. Second, the ICT measures are combined with a unique range of specific output measures – such as crime clearance rates - and complementary assets (skills, organisational structure), which allow the specification and estimation of police departments production function. Third, the empirical analysis carefully combines the basic findings of the research with a wide range of robustness checks to probe the validity of the results against alternative explanations.

The second analysis is by Machin, McNally and Silva (2007), who study the impact of ICT across English schools. The question explored by the paper is whether the adoption of computers in schools can effectively increase students' academic performance. This is a highly relevant policy issue given the considerable ICT investments in schools undertaken by the UK government in recent years. However, the effects of ICT are difficult to identify due to the endogenous allocation of ICT investments by policy-makers. Looking at a panel of several thousand schools observed between 1999 and 2003, the authors provide evidence of a strong relationship between ICT investments and educational performance in primary schools, especially in the teaching of English. This result is in sharp contrast with previous studies across US and European schools, which could not find any empirical support for the benefits of the introduction of ICT in schools[29]. The Machin et al (2007) is notable for its strong identification strategy. More specifically, the authors rely on the introduction of a new funding policy that occurred in 2001, which created an exogenous change in ICT investments available to schools. The exogenous variation was based on area-level variations in funding which gave local educational authorities different opportunities to invest in ICT for local schools. Unfortunately, since this paper is based on area-level variation, the authors are not able to provide any insight on the key characteristics of the schools which were most affected by ICT adoption, or whether significant school organisational or skills complementarities may have impacted the ultimate effect of ICT on performance.

In summary, theoretical considerations suggest that the effect of ICT across public sector industries could be significantly affected by organisational and skill complementarities. Unfortunately, measurement problems and data availability have so far constrained the empirical analysis of these arguments. The few empirical analysis that have attempted to quantify the impact of ICT in public organisations at the micro level suggest that ICT may indeed increase public sector efficiency, but this effect could be mediated by the specific types of organisational practices and skill compositions which are combined with ICT.

(ii) Public Sector ICT Expenditures and Private Sector ICT Take-Up

A question that we would like to address in our empirical analysis is whether public sector spending in ICT might affect the take up of new technologies by businesses. A useful theoretical framework that can be used to analyse this issue is provided by Barro (1990). Barro analyses the role played by generic public sector expenditures in the context of a simple endogenous growth model where public services enter as productive inputs for private producers. A key feature of the model is that the production function shows constant returns to scale to government expenditures and capital taken together, but it has decreasing returns to

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[29] See, for example, Angrist and Lavy (2002), Leuven et al. (2007), Goolsbee and Guryan (2006) and Banerjee et al. (2007).

scale to government expenditures and capital taken separately. This implies that the marginal productivity of private capital will be positively affected by public expenditures, and generates an immediate linkage with investment levels and productivity. However, two caveats are worth noting. First, the ultimate effect of public expenditures on growth depends on the way these expenditures are financed. This is because the positive productivity effect arising from government expenditures might be completely offset by the need to finance public spending with distortionary taxation. Second, when the government maintains a fixed ratio between public expenditures and income (this is equivalent to a fixed income tax), then private investment levels may nevertheless be suboptimal, since businesses fail to internalise the fact that higher investments generate higher output, which in turn translates into higher public expenditures and productivity for everybody.

The Barro model can be easily extended to the analysis of public expenditures in ICT. An immediate way to test the notion that public sector expenditures on ICT might positively affect the productivity impact of ICT investments in the private sector is to estimate the following model:

$$y_{ijkt} = \beta^{c} c_{ijkt} + \beta^{k} k_{ijkt} + \beta^{l} l_{ijkt} + \alpha' x_{ijkt} + \beta^{h} PUBLIC_{kt} + \beta^{ch} (c_{ijkt} * PUBLIC_{kt}) + u_{ijkt} \qquad (20)$$

where *PUBLIC* represents a suitable indicator of country specific government expenditures in ICT. A major challenge in the estimation of this model is that public expenditures in ICT could be related to other country specific omitted factors associated with productivity. To address this concern, we will augment the specification with additional variables capturing country specific characteristics such as economic development, country size and average levels of skills.

(iii) Studying the ICT Intensity of the Public Sector with AMATECH

In this section we analyse the ICT intensity of the Public sector using information drawn from AMATECH. In what follows, we will define as part of the Public sector all establishments classified under the US sic codes 80 (Health services), 82 (Educational Services), 83 (Social services) and the entirety of “Division J: Public Administration” (SIC codes 91-99), which includes primarily legislative services and purely administrative services. It is important to note that the establishments included in this definition might not necessarily be State owned, although they will all be obviously engaged in the provision of public services.

Using this definition, we can identify approximately 77,000 public sector establishments, or 20% of the overall AMATECH sample between 2003 and 2008. The percentage of public sector establishments does not vary much over time (from 18% in 2003 to 23% in 2003), although the public sector coverage does vary significantly across European countries, going from a minimum of 5% in Hungary and Poland, to a maximum of 33% and 40% in Belgium and Norway. The public sector is also characterised by much larger establishments compared to manufacturing and service, with an average of 450 employees per establishments, vs. 250 in manufacturing and 172 in Services.

In Table I.24 we analyse the ICT intensity of public sector establishments. The data shows that public sector establishments are on average more ICT intensive than both manufacturing and services, with an average of 1.32 computers per employees, vs. 0.64 in manufacturing and 1.18 in services (differences significant at the 1% level). Within the public sector, the most ICT intensive industries are by far Education (SIC 82) and National Security (SIC 92), while the least ICT intensive are Health services (SIC 80). These broad averages hide considerable variation across European countries. For example, the ICT intensity of the Education sector ranges from a minimum of 0.60 computers per employee in Poland and Slovenia, to a maximum of 7 computers per employee in Austria.

Panel C of Table I.24 explores in more detail the differences in ICT intensity within Europe, grouping the different countries in four major blocks: Eastern Europe (Czech Republic, Hungary, Poland and Slovenia); Northern Europe (Finland, Sweden, Denmark, Norway, UK, Ireland); Southern Europe (Spain, Italy and Portugal); and Western Europe (Switzerland, Austria, Belgium, France, Germany, Luxembourg and the Netherlands). Panel C shows that Northern European countries are generally more ICT intensive across all sectors, with 1.07 PC per employees versus 0.70 in Eastern and Southern Europe and 0.88 in Western Europe. Interestingly, the gap between Northern Europe and the rest of the countries is particularly stark across public sector establishments, compared to services and, to a lesser extent, manufacturing. More specifically, Northern European establishments have an average 38% more computers per employee than other regions in public sector establishments, while the gap is 30% in manufacturing and 11% in services.

A relevant question is whether the ICT intensity of public sector establishments can play a role in determining the productivity impact of ICT investments in the private sector. More specifically, higher ICT intensity in the public sector might imply easier access to public services via computers, which would generate a complementarity with ICT investments at the firm level. Indeed, the public sector intensity measure derived from AMATECH at the country level is highly correlated with the existing measures capturing the intensity and the quality of E-Government infrastructure across European countries. For example, the public sector intensity derived from AMATECH is highly correlated with the estimated E-government expenditure per capita developed in the framework of the Egep project (2004) and with the survey indexes developed by Eurostat measuring E-government availability and the fraction of business which report to interact with the government via internet in 2007.

A very simple way to test this hypothesis is to augment the standard production function regression with an interaction between firm level ICT intensity and the average ICT intensity of the Public sector, measured using AMATECH and aggregated at the country level. Table I.25 shows the results of estimating equation (20) outlined above. Column (1) shows the baseline regression with ICT capital appearing linearly. In column (2) we augment the specification with the interaction between ICT capital at the firm level and the public sector ICT intensity of the public sector. The interaction terms appears with a positive but marginally significant coefficient (coefficient 0.021, standard error 0.015). In column (3) we introduce an additional interaction between firm level ICT capital and country level measures of GDP per capita to verify whether we can disentangle the effect deriving from higher levels of public sector ICT intensity from other sources of externality deriving from high levels of income per capita. The ICT*GDP per capita interaction is not significant in its own, but it reduces the significance level of the interaction of firm level ICT and Public sector ICT intensity even further. Interestingly, however, the magnitude of the coefficient remains substantially unchanged (coefficient 0.021, standard error 0.019).

In summary, public sector establishments appear to be significantly more ICT intensive than their private sector counterparts. There are important differences in ICT intensity within public sector industries and across European countries, with public sector establishments in Northern Europe appearing to be much more ICT intensive than in Eastern, Southern and, to a lesser extent, Western Europe. A very simple analysis of the data does not show any evidence of complementarities public and private ICT investments.

E THE EFFECT OF ICT ON CONSUMPTION PATTERNS AND PRICES

Understanding the impact of ICT on the consumption-side of the economy requires a different methodological perspective to that followed elsewhere in the report. Specifically, while other questions can be answered with reference to comprehensive firm level data, empirical research on the consumption-side of the economy involves a wider range of fragmented, industry-specific data.

In the sections below we take two approaches. Firstly, we review the existing literature on the topic which is generally focused on industry and goods-based case studies. Secondly, we conduct a basic analysis of consumer prices in the UK focusing on groups of goods that are likely to have been affected by ICT-related innovations. These groups are firstly, electronic consumer goods in general (eg: information processing and audio-visual equipment); books ; and recorded media.

(i) Literature on ICT and Prices

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 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. 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 costs. More indirectly, ICT could also affect the production and especially distribution costs of goods, and although there are numerous examples of this – Amazon.com built the largest, fully automated warehouse at the time and consequently realized significant cost savings vis-à-vis conventional, “brick-and-mortar” retailers, 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, i.e. 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 organisation 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.

Individual Studies

Bailey (1998), for example, looks at CD ad book prices and finds that online price dispersion is considerably high, and that prices of these products on the Internet were higher than those in the conventional channel. In a similar vein, Lee and Gosain (2002), compared price dispersion of music CDs between internet retailers and notable "brick and mortar" retailers in 1999 and 2000, finding that prices were comparable for current hit albums but lower for other products.

Similar conclusions were reached by Erevelles, et al (2001), who explored the pricing behaviour of Internet versus traditional firms in the vitamin industry, and by Scholten and Smith (2002), who compared price dispersion levels in traditional retail markets of 1976 with those in Internet retail markets of 2000. Opposite conclusions were instead reached by Brynjolfsson and Smith (2000), who looked at book and CDs sold through 41 online and offline retail outlets from February 1998 to May 1999. When they considered retailer posted prices weighted by their respective web traffic (a proxy for market share), they found that price dispersion was smaller online than it was offline.

An interesting cross-country study is provided by Clay and Tay (2001), who studied prices for 95 textbooks sold in nine online bookstores in the U.S., Canada, U.K., and Germany in 2001. They document a substantial amount of price dispersion across these countries, even within different branches of Amazon.com.

Even within online retailers, price dispersion appears to be remarkably high. Clemons, Hann and Hitt (2002) studied prices of airline tickets quoted by online travel agencies in 1997, and found that price dispersion was significant. Bakos et al. (2000) also found significant dispersion in trading cost for online retailer brokerage service. In summary, internet markets seem to exhibit no smaller price dispersion than traditional markets. However, the findings may be a result of the developing nature of Internet markets. For example, Brown and Goolsbee (2002) investigated the impact of Internet comparison shopping on life insurance market during 1992-1997. They found that price dispersion initially increased with the introduction of the Internet search sites, but then decreased as Internet usage spread.

ICT has also affected the structure of firms' product portfolios. Recent studies by Brynjofsson, Hu and Simester (2007) and Ghose and Gu (2006) have examined how falling consumer search costs have affected the distribution of product sales. Using data on a large multi-channel retailer, Brynjofsson et al (2007) compares products sold in the internet sales channel to those sold in conventional channels. They find a less skewed distribution of product sales in the internet channel .That is, there seem to be more low-volume niche products in cases where search costs are low (i.e.: in the internet sales channel). This difference is significant even when controlling for consumer differences and is stronger among customers with more experience of internet usage. Brynjofsson et al (2007) argue that if these trends persist they "portend an ongoing shift in the distribution of product sales". However, it remains an open question as to how far this niche effect can be replicated across more homogenous goods.

(ii) Impact of ICT on Producer and Retail Prices

The literature on prices and ICT described above has focused in most cases on case studies of particular goods and markets. However, there is a more general question to be answered about the potential impact of ICT on price setting across many goods and services in the economy. While there has been much discussion of the role of falling ICT equipment prices in the ICT producing industries (eg: Jorgenson et al 2008) the influence of ICT on prices in other industries has received much less attention. In the sub-sections below we first look at the impact of ICT investment on price prices in the US and Europe. This analysis is focused on the manufacturing sector (since producer prices are only defined for these industries) while the second section discusses changes in retail prices for disaggregated goods.

Producer Prices

The important question here is whether investment in ICT may be associated with falling prices in industries outside of the dedicated ICT-producing industries. To explore this question we use a combination of producer price data for the US and Europe as well information on trends in ICT investment taken from our Harte-hanks technology database. The analysis of producer prices is important in this case because these prices represent the "factory gate" price of goods and price reduction here could be expected to flow through to wholesale and retailing industries, depending on mark-ups.

Specifically, the approach here is to regress the change in producer prices on a measure of ICT investment (in this case the change in the number of PCs per employee). We also add a measure of import penetration as an additional variable. This is important because changes in imports (specifically the large recent increase in Chinese imports across many manufacturing goods categories) has been seen as a major force in determining changes in producer prices in recent years. The inclusion of this variable for import penetration therefore represents a test for the magnitude of ICT's impact on producer prices.

The results of this analysis of producer prices are shown in Table I.26, with the upper panel reporting results for European 2-digit data up to and the lower panel providing estimates based on 4-digit US data[30]. The first four columns in each panel use 2-year and 4-year differences and include the change in Chinese import penetration and the log change in industry PC intensity as the main variables. These regressions indicate significant effects of import penetration and ICT for Europe and the US in the 4-year difference specifications. In terms of magnitude these effects need to be calculated at the mean to effectively compare the potential influence of each variable on producer prices. In Europe, import penetration has a total effect of -1.2% on the price level of a given 4-year period with ICT also accounting for around a -1.2%

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[30] The 4-digit Eurostat producer price data is characterised by a large number of missing values across countries. We therefore focus on the more complete 2-digit data in the European case.

fall in prices at the mean[31]. For the US, import penetration accounts for around -1.1% of the fall in producer prices while ICT accounts for -0.6%[32]. These results are suggestive of a strong role of ICT in determining price levels with the magnitude of the ICT roughly equal to the effect of imports in the European case and still standing at 60% of the import effect for the US. Finally, columns (5)-(6) of Table I.23 use dummy variables to measure price changes in the ICT-producing industries, showing the magnitude of the fall in producer prices for these industries as similar across the European and US samples.

This finding of a link between ICT and producer prices is a new one in the literature. The most likely mechanism for this ICT-led fall in prices relates to productivity growth. That is, by increasing productivity ICT has expanded "potential output" and relieved supply-side pressures on producer price inflation. The results in Table I.26 provide some hard evidence of this and we explain how this can be extended in the section on recommendations for future research.

Retail Prices

Table I.27 reports the results of an analysis of retail price data from Eurostat across the 13 countries with the most complete data. The aim of this analysis is to examine whether particular goods that may have been affected by ICT-related goods have experienced sharper falls in prices than other unaffected industries. Furthermore, we test for country heterogeneity by testing for interactions with country-level variables measuring the strength of product market regulation, the degree of broadband penetration, and country GDP.

The two groups of goods that we posit as being potentially affected by ICT are Electronic Goods and Equipment (denoted as "ELECTRO") and Consumer Media Goods (a group consisting of books, newspapers and electronic content media). The first group of goods are likely to have been directly affected by the falls in prices seen in the ICT-producing industries. It is therefore interesting to measure the extent of price falls for these goods since this has implications for consumers. The second group of goods are selected as those goods most likely to have been affected by ICT usage in consumer markets. Specifically, this group includes books, newspapers and recorded media (ie: CDs, DVDs). These are the main categories of goods examined in the case studies discussed above since they have been subject to high profile trends in online retailing, delivery and/or file-sharing.

The results given in Table I.27 show sharp falls in prices for both Recorded Media and Electronic Goods and Equipment. Respectively these are approximately a -10.4% and -27.4% fall over the pooled 3-year periods used in these regressions. This translates as an annualized rate of -3.4% and -9.1%. In contrast, books and newspapers increase either a neutral change in prices relative to other goods (in the case of books) or a relative increase (newspapers/magazines). The most likely explanation of the result for newspapers probably lies in a combination of quality changes (ie: increase in the size and accessories accompanying printed media) and increases in cover price to ameliorate the effects of falling circulation. These circulation falls may be a function of online news delivery and competition but this issue is outside the scope of the data available here.

The results in columns (2)-(5) indicate a minimal role for broadband penetration and product market regulation in explaining country differences in retail price changes. There is some evidence that higher broadband penetration is associated with small additional falls in prices (column(2)) but the results are neutral for the product group interactions shown in column(5). Higher product market regulation is associated with small price increases but again the results for the product group interactions in column (5) are ambivalent. Country-by-country estimates are reported in Table I.28. This indicates that falls in electronic goods prices were highest in

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[31] These magnitudes are calculated as the mean change in the variable over the sample multiplied by the given coefficient. In the case on imports this is 0.026*0.482 while for ICT it is 0.2*-0.06.

[32] For the US the magnitude calculations are 0.039*-0.274 for imports and 0.1*-0.032 for ICT.

Sweden, the UK and Ireland while falls in recorded media prices were greatest in the Netherlands, Greece and the UK. Table I.28 also shows that the increase in newspaper and books prices across countries is uneven with some countries recorded strong increases while others experienced either neutral effects or price falls.

Practically, it is hard to gauge the importance of these types of changes in household expenditure. Table I.29 reports some summary statistics for a group of ICT-related goods that are compatible with the categories of retail prices examined in Table I.27 and I.28[33]. This indicates that our basket of ICT and related goods comprises around 5% of household expenditure in total. Hence the *direct* impact of ICT-related price falls on household budgets is likely to be limited, even allowing for income and substitution effects.

In concluding this analysis some strong caveats must be noted. Firstly, since it is difficult to map industry-level variables into retail prices it is hard to decisively model the impact of forces such as import penetration and product market regulation on prices. Secondly, the classifications used in Table I.27 may not capture the full range of goods heavily affected by ICT. As the earlier Table I.26 shows ICT investment is associated with falls in producer prices across the full range of manufacturing industries. That is, the effect of ICT on retail prices may well be spread out across a rage of products rather than the high-profile candidates considered here.

SUMMARY OF SECTION I

- We find a large impact of ICT on firm productivity. Importantly, this impact is larger than would be expected given ICT's average share in firm output. This result consistent with other microeconomic studies and is indicative of potential "complementary factors" that are closely associated with the use of ICT. As a central finding, this raises questions about the heterogeneity of the effect of ICT on firm productivity.

- In terms of heterogeneity, we do not find any systematic effects on the basis of firm size, firm age or region. However, there are large additional effects of ICT present in the ICT-using industries that have also been the focus of macroeconomic studies. Again, these effects are larger than would be expected given the share of ICT in firm output.

- In a new research design, we test for the presence of ICT-related spillovers. This is an important question for establishing the rationale for ICT-related economic policies. If there are significant spillovers from the accumulation of ICT capital then this creates a rationale for subsidizing ICT investment in the same fashion as R&D. While we find evidence that firms in industries and regions with higher ICT usage are more productive this finding is not robust to the inclusion of essential controls. And while there is some robust evidence for peer or network effects in ICT adoption this does not feed through to productivity. Arguably, this is because ICT is an embodied technological good and does not have the same, powerful knowledge creating properties as R&D investment.

- Empirical models of ICT investment indicate that it shares many similar properties with other types of physical capital investment. There is however evidence that ICT responds more quickly to demand shocks.

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[33] Note that we are not able to directly match categories across these two tables because they are based on different classification systems.

- Our analysis of establishment employment growth and exit indicates that ICT has a significant role in the process of reallocation. “High-tech”, ICT-intensive establishments are more likely to grow and less likely to exit. This effect of ICT still prevails even when other important controls for skills (proxied by wages) and firm productivity are included in empirical models. We therefore conclude that ICT matters for firm selection, a finding that is not prefigured in the existing macroeconomic literature.

- In terms of adoption we find that multinational status is an important flag for high-tech firms, with 1 in 10 more computers per worker. Cross-country differences in technology adoption (as measured by PC intensity) seem to be minimal after controlling for industrial composition and fixed regional characteristics. There is a “digital divide” between Western and Eastern Europe of approximately 2 computers per 10 workers but differences within Western are limited and not significant in most cases.

- On spatial economic issues, we find that ICT *decreases* geographical concentration for manufacturing industries in our UK-focused study. We also conduct a US-focused study on the production of innovations and role of universities, an important vehicle for technology policy across the OECD. Our evidence indicates that distance still matters for knowledge flows and that universities are important for local innovation. However, knowledge diffuses more quickly from ICT-related innovations thereby limited the scope for policy to induce clusters of ICT-producing industries.

- ICT has had an effect on prices outside of the type of goods that are specifically associated with ICT. This includes producer prices. ICT investments in Europe and the US have been associated with major falls in producer prices – the “factory gate” prices that underpin retail prices. These falls have taken place not only in the ICT-producing sectors but also across other manufacturing industries. ICT investment is associated with a 0.3% per year fall in European producer prices and is associated with a 0.15% per fall in the US. The magnitude of this effect is comparable to the effect of low wage country import penetration. In the case of Europe the ICT effect is as large as the import penetration and in the case of the US it is half as large.

- Popular debate regarding the impact of ICT on consumer prices has focused on the availability of cheaper electronic goods and the rise of online retailing and delivery. While recent academic studies have focused on case studies of particular goods and markets there has been less of a focus on potential economy-wide effects. We find evidence of significant falls in prices for Recorded Media and Electronic Goods and Equipment. These falls have been of the order of -3.5% per year for Recorded Media and -9% per year for Electronic Goods and Equipment. In contrast, the prices of books and newspapers have either moved neutrally with prices or increased slightly. It must be noted that based on the evidence for producer prices, it seems that ICT is having an effect on prices outside of the obvious consumer price categories we consider here.

II THE ROLE OF ICT IN KNOWLEDGE INTENSIVE ACTIVITIES

The idea of the “knowledge economy” and “knowledge capital” has been central to growth-related policy discussions since at least the mid-1990s. ICT has had a prominent place within these discussions, largely as a result of its perceived role as a general purpose technology underpinning the development of many different inventions and micro-innovations. The leading empirical approach to formalising the role of the knowledge economy in growth is arguably represented by the work of Corrado, Hulten and Sichel (2006). Their contribution is to formally incorporate “intangible capital” into a growth accounting framework. The main components of their definition of intangible capital are given in Table A5 in Appendix A and includes three broad categories: computerised information (including purchased and own-account software); innovative property (R&D and its outputs); and economic competencies (firm-specific assets). Using this framework Corrado et al estimate that the value of US intangible investment in the 1998-2000 period was very large – worth approximately 11.2% of existing GDP and 1.2 times the value of tangible capital spending. Significantly, they show that the contribution of computerised information to total intangible investment rapidly increase in the 1990s from approximately 23.2 billion in 1980-89 to 85.3 billion in the 1990-99 period.

However, in practical terms these insights with respect to intangible capital are still very recent and concentrated in macroeconomic growth accounting methods and data sources. Therefore in the sections below we offer a range of empirical approaches for understanding the “micro-to-macro” dimensions of intangible capital and the overall role of ICT in the knowledge economy. The concept of intangible capital is important to this discussion because it allows us to integrate the discussion of ICT’s role in knowledge intensive activities across a number of areas. These areas are: *(A)* ICT’s direct contribution to knowledge capital in the economy; *(B)* the role of ICT in supporting innovation, particularly that related to various measures of innovative property; *(C)* the special role that ICT has in facilitating collaborative research by lowering communication costs; and *(D)* the relationship between ICT and firm-specific economic competencies (for example, management practices and organisational structure). Finally, as a technical note, in the discussions below we use the term “knowledge capital” to indicate the sum of high-tech tangible capital (such as ICT hardware) and knowledge-based intangible capital.

A KNOWLEDGE CAPITAL AND ICT

As shown in some major recent studies (Corrado, Hulten and Sichel (2006) for the US and Clayton, Borgo and Haskel (2009) for the UK) ICT has had major role in driving the development of the economy-wide stock of intangible capital, particularly since the mid-1990s. In the discussion below we outline two microeconomic approaches for understanding both ICT’s direct contribution as an element of knowledge capital and its indirect or complementary role with respect to other types of knowledge capital, specifically R&D.

The contribution of Corrado et al (2006) highlighted the quantitatively important role that ICT plays in total intangible capital investment. Industries and sectors with high levels of intangible ICT capital can therefore be characterised as a “knowledge intensive” subset of the ICT-using industries. Following Corrado et al (2006) and other growth accounting contributions (see in particular Chesson and Chamberlain (2005) for the UK) we can further breakdown the contribution of ICT in the firm level production function. For the purposes of simplicity first consider an extension of equation (1):

$$Y = AF(X) = AF(L, K, C^1, C^2, C^3, M) \tag{21}$$

The only change here relates to ICT capital which has been disaggregated into three components, one class of tangible ICT capital and two classes of intangible capital. These components are: tangible ICT investment in hardware (C^1); intangible investment in purchased software (C^2); and intangible investment in own-account software (C^3). This three-part division of ICT capital directly follows that of Corrado et al (2006) and Chesson and Chamberlain (2005). In terms of an estimated microeconomic production we can envisage that (1) would be operationalised as a variant of equation (8) from Section I:

$$y_{ijkt} = \beta_1^c c_{ijkt}^1 + \beta_2^c c_{ijkt}^2 + \beta_3^c c_{ijkt}^3 + \beta^k k_{ijkt} + \beta^l l_{ijkt} + \alpha' x_{ijkt} + u_{ijkt} \qquad (22)$$

As before the variables *y*,*c*,*k* and *l* denote the logarithms of real output, ICT capital, non-ICT capital and labour inputs respectively. The obvious difference is that we have sub-divided ICT capital into three components, each estimated with separate β^c coefficients. Practically, the main issue with estimating a model such as (22) is obtaining good measures of the three types of ICT capital. This is challenging enough at the macroeconomic level before even considering a firm level approach. The implementation by Chesson and Chamberlain (2005) makes use of input-output tables to estimate C^2 and measures C^3 in terms of the "costs of production" (ie: the remuneration to workers producing own-account software).

Practically, some of the key building blocks for measuring intangible ICT capital are present in the AMATECH data and we present some results in Table II.1. In this table we construct indicators of tangible and intangible ICT capital and test their effects in an OLS production function[34]. The results are quite striking and consistent with the macroeconomic growth accounting literature mentioned above. The first column shows the effect of our baseline measure of tangible ICT Capital (computers per worker) estimated using the sub-sample with clean software and ICT staff data. In column (2) we introduce our first measure of intangible ICT capital – the ratio of ICT-related staff to total employees. This measure of ICT-staff includes employees in company ICT departments as well as ICT-development staff (ie: in-house programmers). As such, the ICT-staff variable is included as a proxy for a given company's capacity to develop own-account software and other firm-specific ICT resources. This variable is for ICT staff is highly significant with a coefficient of 0.086 (0.013). Furthermore, including this variable leads to a fall in the ICT capital coefficient of over one-fifth (from approximately 0.227 to 0.199 in column (2)). One interpretation here is that column (1) was picking up the effect of the omitted intangible components of ICT capital. It is possible that our ICT staff measure is picking up the effects of skill on productivity more generally so in column (3) we control for the firm average wage as a proxy for this effect. The term for ICT staff is still significant however with the coefficient falling slightly to 0.067 (0.013).

The next panel (B) in Table II.1 includes an index of software technologies at the firm-level as a measure of intangible investment in purchased software. These software technologies are: Enterprise Resource Planning (ERP-CRM)[35]; Databases; Industry-Specific Software; Development software; and Groupware. The presence of each technology is flagged with an indicator variable and we add these up into a 1-5 index to construct a proxy for total investment in software. The linear effect of this Software Index variable is weakly positive and small in magnitude. A potential explanation for this lies in the "co-invention" argument. This is the idea that the adoption of a technology is not sufficient to realise its full economic potential – other complementary investments in organisational and human capital need to be made to make the technology effective. We therefore interact the software index with ICT staff in the following column to test for complementarities. In this case, the coefficient for the linear Software Index rises by a large amount but is not quite significant in statistical terms.

In the final panel (C) we posit a dummy variable indicator for the presence of advanced network technologies (e.g. leased lines, frame relays, local area networks) since this could be considered as a distinct form of tangible ICT capital. The Network-tech indicator is strongly

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[34] This focus on cross-sectional estimates is designed to avoid the additional measurement error problems that emerge from relying on time-variation in panel data (Griliches and Mairesse 1997).

[35] The customer-relationship management version of ERP software is used for the software index in this case since it is the type with the most consistent definition across time in the Harte-Hanks data.

significant with a coefficient of 0.109 (0.013) although the inclusion of this variable does not dramatically cut into the baseline coefficient for ICT capital. However, the next column does show evidence of potential complementarities with the ICT staff component of capital. Overall, the two conclusions of Table II.1 are firstly that the baseline ICT capital measure is proxying for other components of intangible ICT capital and secondly that there may be additional effects due to the own-account software and network technology components we have defined. These additional effects are of course subject to the caveat that the given coefficients still reflect above-normal returns (as per section I-A) and that the estimates are subject to various endogeneity biases.

The second major contribution of ICT capital in this context lies in its indirect contribution through complementarities with other types of knowledge capital. In line with the Corrado et al (2006) taxonomy described in Table A5 we focus on ICT's complementarities with innovation (specifically R&D and patents) and firm level economic competencies (management practices, skills and organisational structure). The issue of firm level economic competencies is extensively discussed in sub-Section D below so here we concentrate on complementarities with "innovation capital". As our discussion implies, patents (*P*) and R&D expenditure (*R*) are the two most common measures of innovation capital. Assuming these as our two measures, we will denote innovation capital as *G* and this leads to the general production function:

$$Y = AF(X) = AF(L, K, C, G, M) \qquad (23)$$

where we have suppressed the distinction between tangible and intangible ICT capital and the other terms are denoted as before. Of course we can now generalise this as a microeconomic production function with interactions as follows:

$$y_{ijkt} = \beta^c c_{ijkt} + \beta^k k_{ijkt} + \beta^l l_{ijkt} + \alpha' x_{ijkt} + \beta^g g_{ijkt} + \beta^{cg}(c * g)_{ijkt} + u_{ijkt} \qquad (24)$$

where *g* is the logarithm of the innovation capital measure *G*. The first issue here relates to the measurement and subsequent linear (or "direct") effects of *g*.

Griliches (1998) describes the main issues involved with using R&D as an input in a microeconomic production function. R&D measures are typically entered using a multi-period lag structure since it takes time for R&D inputs to be translated into productivity enhancing innovations such as new inventions or product and process innovations. Similarly, depreciation rates and price deflation issues must be taken into account when estimating the effect of R&D[36]. The use of patent stocks as a measure of *g* is less common in the literature, and in contrast to R&D, patents are an innovative output (ie: inventions with legally declared property rights) rather than an input measure. But many papers have shown that patents and R&D are highly correlated (e.g. Hall, Jaffe and Trajtenberg, 2005), so using patents stocks is a reasonable proxy when R&D is unavailable (as it is for most European firms as unlike the US reporting standards on R&D are not mandatory even for publicly listed firms).

Bloom and Van Reenen's (2002) UK study is one paper that does use patents as a measure for *g* in the production function. They include both unweighted and cite-weighted patent stocks in a firm level production function finding an elasticity of 0.03 (implying that a doubling of the patent stock would increase productivity by 3%). By comparison, the output elasticity of R&D is typically estimated to be in the range of 0.05-0.10 (Griliches 1998) with the recent application by Bloom, Schankerman and Van Reenen (2009) estimating an output elasticity of 0.059 for listed US firms in COMPUSTAT since 1980.

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[36] As Griliches (1998) notes the depreciation of R&D capital is affected by both obsolescence (due to the arrival of new innovations by competing firms) as well as "leakage" (as formerly firm-specific knowledge is diffused through an industry). In terms of price deflators, these are often hard to define for some of very specialised R&D intensive industries (eg: health, space or defence).

The direct effects of *g* in equation (24) are augmented by the interaction effect as measured by the coefficient β^{cg}. Of course, given sufficient data equation (24) can be expanded to include separate terms for tangible and intangible ICT capital alongside the associated interactions with *G*. The theoretical rationale for such an interaction is not immediately clear and this type of interaction is not commonly estimated in the literature. The most obvious link lies in the potential interaction between *G* and intangible ICT capital. It is credible that higher levels of intangible ICT capital (particularly that associated with own-account software) would complement a firms overall R&D efforts. It must be noted though that the interpretation of these linear and interaction terms is subject to endogeneity.

We estimate a version of equation (24) in Table II.2. In this specification we use the firm-level patent stock as our measure of innovative property, *g*. The first two columns give us the linear effects of ICT capital (defined here as computers per worker – the tangible "hardware" capital measure) and the patent stock for this sub-sample. The ICT capital coefficient is lower than for previous full sample specifications but the result for the patent stock variable is in line with the studies discussed above. Column (3) includes both terms in a linear specification. The skewed nature of the patent stock variables requires us to move to a discrete specification to look effectively at interactions effects. Here we define a dummy variable for all those firms in the top half of the patent stock distribution, that is, the most innovative firms in the sample. This dummy variable is significant with a coefficient of 0.076 (0.036) in column (4). The interaction effect between ICT capital and this dummy variable for highly innovative firms is also positive but not significant, providing tenative evidence of complementarities between ICT capital and firm patent stocks. As discussed above, this is probably to be expected – theoretically there is no strong reason to expect powerful complementarities between these components of knowledge capital at the firm-level.

B ICT AND INNOVATION

The above discussion of complementarities between ICT and other forms of knowledge capital canvassed the idea that ICT capital may support the R&D and innovation efforts of firms. In this section we address this question more directly by looking at ICT's role as a determinant of firm level innovation. The main focus of this section is therefore an innovation equation describing the relationship between various innovative outputs and a range of firm level inputs (including ICT). We do this in two ways. Firstly, we outline an innovation equation focusing on patents as the main outcome measure. This follows the methodologies developed in the well-established literature on patenting (for example, Griliches 1990; Blundell, Griffith and Van Reenen (1995)). Secondly, we outline a new approach to modelling product and process innovation that utilises the software information available in our AMATECH database.

(i) Patenting and ICT Capital

The value of patents as a measure of innovation is surveyed in detail by Griliches (1990). As he points out the main value of patents as a measure of innovation is that they represent a "minimal quantum of invention" that has passed the scrutiny of patent examiners and is of revealed economic importance to a firm. Pakes and Griliches (1984) formalised a patenting equation as a representation of a "knowledge production function" relating a latent knowledge output (proxied by patents) to a range of inputs.

However, the exact role of ICT in fostering the types of innovations measured in patents is not immediately clear. As pointed out above, the intuitive idea is that ICT could be considered as some type of advanced, technology-based capital input – an adjunct to R&D in a knowledge production function. Furthermore, firms operating in environments where their neighbours (in terms of industrial, technological or spatial distance) are also intensive users of ICT could benefit from spillovers in the production of knowledge. We test this latter spillover hypothesis in Table II.3. Specifically, we define an innovation equation of the form:

$$\ln(PATSTOCK) = X'_{jkt}\beta_1^p + Z'_{ijkt}\beta_2^p + \beta_3^p SPILL_{jkt} + \eta_i + \tau_t \qquad \textbf{(25)}$$

where ln(PATSTOCK) is a measure of the patent stock and *X* is a vector representing firm-level characteristics that could affect knowledge production (ie: firm size, sales, capital) while *Z* is a vector of industry characteristics such as R&D inputs and import competition. We use the patent stock rather than the flow of patent counts so we pick up cumulative changes over time. The first column shows the effect of our ICT spillover terms (4-digit industry ICT intensity) only including controls for country-year effects. The next column includes an industry-level control for R&D intensity obtained from OECD data. This results in a sharp fall in the SPILL coefficient from 0.309 (0.076) to 0.233(0.073)[37]. Column (3) then includes firm-level controls without seriously effecting the SPILL coefficient. However, the SPILL coefficient does fall by more than half when we include industry fixed effects in column (4). This is a striking result insofar that the SPILL coefficient here is identified from time and country variation. However, in the final column we include firm fixed effects and the SPILL effect disappears. In conclusion, both these results and those in Table II.3 imply that it is unlikely that ICT capital is having a decisive impact on the type of innovation measured by patenting. Instead, ICT's major role in firm-level innovation probably lies in its usage as a tool in product and process innovations that are not codified by formal intellectual property rights. We now turn to this issue.

(ii) ICT as a Vehicle for Product and Process Innovations

While patents are useful as measures of innovation, the obvious criticism is that they only measure a particular segment of all innovations, namely those associated with original, legally codified inventions. Firms also deploy a wide range of innovations in their products and cost structures that go unmeasured in the patenting framework. The literature on innovation has faced a difficult challenge in attempting to quantify these product and process innovations. One notable measurement exercise was the long-term project by the Science Policy Research Unit (SPRU), which used a classification system led by expert opinions of individual innovations[38]. More recently, the Community Innovation Survey (CIS) has included questions on the incidence of product and process innovations. A major problem with the approach in the CIS is that it is not focused on tangible products or specific examples of product and process innovations. In this section we outline a new approach based on the usage of particular software programmes. Importantly, we nest this within an overall model, first discussing the firm level decision regarding product and process innovation, followed by an example based on two types of software reported in the AMATECH database.

One of the major questions regarding the firm level innovation decision is whether different types of innovation (e.g. product and process) preclude each other, or if they are instead complementary. There are arguments for both: the lines of argument suggesting substitutability are that i) firms are typically cash constrained, which makes it difficult for them to conduct two types of innovation at the same time, and that ii) managerial capabilities (especially at the middle management level) are limited and the demands on an organisation trying to implement one type of innovation are already so high that implementing both simultaneously would be prohibitively costly. The arguments in favour of complementarity are that i) both product and process innovations tend to increase equilibrium output and therefore increase the profitability of the other innovation, and that ii) the capabilities enabling a firm to deal with one type of innovation will probably also be helpful in generating profits out of the other type. In other

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[37] Note that one potential reason for this is that the SPILL term in this case is defined at the country-SIC4 level and features many more points of variation than the R&D measure (which is given at the ISIC 2-digit level by the OECD).

[38] Experts were asked to identify innovations as "the successful commercial introduction of new products, processes and materials introduced in Britain between 1945 and 1983". See Simonetti, Archibugi and Evangelista (1995) for a discussion of the SPRU database and Van Reenen (1996) for a firm-level study.

words, a firm that is good at product innovations is also likely to be good at process innovations.

Which of the two views is true is difficult to establish theoretically, and even empirical studies are fraught with problems of sample selectivity, precise delineation of different types of innovation and subjective responses.[39] Further, most existing studies are based on two assumptions: the first is that innovations are created and used in the same organisation. This implies that there are no problems of incentive (in-)compatibility across organisations. The second assumption is that innovation generation and adoption is the same process. This practically assumes away the problem of innovation adoption – once an innovation is there, it is adopted, and an innovation is only created if it is profitable. We believe that it is especially important to distinguish between these features in a European context, as European companies are frequently considered fairly capable at coming up with innovations, but much slower than their US counterparts in adopting them. We therefore focus on the second part of the innovation process – innovation adoption. In this report we provide a case study of French car dealers as an example of the type of study that can be applied in other contexts where well-defined regulatory changes can be mapped to firm-level data.

This again poses the methodological problem of identifying product and process innovation. We address this problem by recognising that ICT adoption by firms occurs with the aim of improving firm profitability by either enhancing the revenue-generating ability of the firm (product innovation) or lowering the operating costs of the firm (process innovation). To be able to arrive at robust conclusions about the relationship between product and process innovations, we have to identify two forms of ICT that are useful proxies for product and process innovations. Given that most hardware serves as a general purpose technology (GPT), it is useful to focus on software adoption which typically changes a more narrowly defined part of the firm's operations. In this study, we select human resource (HR) management software as a cost-reducing (process) innovation, and applications development software (APPS) as a demand-enhancing (product) innovation.

In this example, 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. Thus HR accounts for process innovation in our econometric model. While this classification can be contested it is also hard to make the case that HR management software can be categorized alternately as a product innovation. That is, HR management software bears directly on the management of the firm labour force rather than any specific products sold by the firm.

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, customised software applications. Thus, APPS effectively provides a user interface and toolbox for programmers. Applications are highly industry-specific, highly specialised, and often support mass customisation like "car configurators" (web based software where potential buyers can customise their desired automobile) or specialised software components that enter the end product. Typically, APPS facilitates applications development where no ready-made applications exist or where its customisation would be too expensive. Ready-made applications dominate the market for improving the efficiency of standard business processes (like HR management), and customisable products like SAP ERP (an enterprise resource planning system that supports typical functions in an organisation such as finance, controlling, materials, and sales), regulates industry-specific material and information

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[39] This is true for example for most of the studies based on the Community Innovation Survey (CIS).

flows across different processes within the firm. Therefore, it seems plausible that APPS software will most commonly be used to develop fully customised 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. By the latter point we mean that the actual usage of the application for customization within the firm is idiosyncratic and therefore hard to outsource. We thus believe that firms adopt application development software for revenue-enhancing reasons so that APPS account for product innovation in our econometric model.

The identification of different software types as product and process innovations is crucial for identifying the interactions between these two types of innovations. However, simply looking for correlations in usage creates exactly the problems frequently encountered by other researchers – unobserved heterogeneity may be the key factor driving joint adoption, which essentially leaves the researcher guessing as to which role is played by technological complementarities and which by unobserved heterogeneity. To deal with this, we have developed an econometric model (outlined in Appendix B) that accounts both for potential complementarities and unobserved heterogeneity.

As an empirical application of our approach, we estimate the effect of an increase in competitive pressure on French car dealers triggered through the expiry of EU Regulation 1475/95 which previously allowed car manufacturers to restrict competition in the car dealer market through independent resellers. This exogenous (to the car dealer industry) increase in competitive pressure serves as a useful testing ground for our econometric as we can distinguish between different competitive regimes and their impact on firms' patterns of adopting product and process innovations.

Table II.4 gives the unconditional complementarities (i.e. not controlling for other firm or market characteristics) and shows that there appears to be a positive correlation between the scale of the firm (x_y) and the adoption of product (or growth-enhancing) innovations (x_d). This could, however, be driven by factors not controlled for in Table II.4 or unobserved heterogeneity, and in particular by the fact that choices of scale and product and/or process innovations are made simultaneously. We therefore estimate our full model of an adoption equation each for product and process innovation, a scale equation, and finally an equilibrium profit equation.

Table II.5 presents the estimation results of our full model. To illustrate the usefulness of our approach, Model I ignores unobserved heterogeneity and complementarities among innovation adoption and scale, while Model II includes complementarities but not heterogeneity, Model III allows for unobserved heterogeneity but not complementarities, and Model IV is the completely unrestricted model. Likelihood ratio tests favour this least restrictive model, suggesting that both complementarities and unobserved heterogeneity contribute to explaining variation in the adoption behaviour of firms.

Our results are informative in two respects: First, they show that an increase in competitive pressure as identified by us has no independent effect on the adoption of either product or process innovation, but on the scale of car dealers. In essence, car dealers were previously restricted in their growth by not being allowed to open up branches outside their allocated territory and by not being able to sell spare parts to resellers. Lifting this restriction allowed them to grow in these two ways.

Second, the increase in scale identified triggered a change in the adoption behaviour of firms. In essence, larger-scale firms are more likely to adopt product innovations ($\delta_{dy} > 0$ at the 1% level), which was expected given the type of product innovation we have identified above. Conversely, the adoption of product and process innovations are substitutes ($\delta_{dc} > 0$ at the 1% level), so that firms appear to choose one of the two, but not both. This suggests that there may be managerial or financial limitations that prevent contemporaneous adoption of multiple innovations.

In summary, our results suggest that there are significant complementarities across different types of innovations and other firm strategies. A thorough study of, say, the impact of competition on adoption of information technologies, would have to make sure that not a single technology is studied, but that interdependencies with related technologies and auxiliary firm strategies have to be taken into account.

C. ICT, COMMUNICATION COSTS AND COLLABORATION

The major operational benefits of ICT can be summarised in terms of two functions – computation and communication (Autor, Levy and Murnane 2003). The computational functions relate to the mass storage of information as well as the processing of routine tasks[40]. The second function of communication has come to the fore since the 1990s with the rise of internet technologies. New communication technologies have facilitated the co-ordination of tasks. This co-ordination function has an obvious effect in terms of facilitating collaborative research activities both within the firm and between firms (or between firms and the public sector). The most decisive empirical demonstration of the between-firm collaboration effect can probably be found in Agrawal and Goldfarb (2008) which examined the effect of early internet technology on scientific collaboration between university engineering departments in the 1980s and 1990s. Interestingly, they found that that these early internet technologies increased the probability of adoption by approximately 40% and facilitated joint activity between so-called first and second-tier universities[41]

However, these types of between-firm collaboration effects are very difficult to measure empirically. Credible measurement requires very specialised data (i.e. showing how firms interact) and a good research design (ie: one involving an intervention where communication costs fall). In contrast, it is possible to build a window into within-firm collaboration processes by looking at the productivity effects of specific collaborative technologies.

We have identified a number of these technologies including: within-firm networks (such as leased-lines and frame relays); customer relationship management ERP software; and finally workflow tools. The first technology captures the overall facilities available for within-firm communication while the ERP technology is a tool for managing specific relationships in terms of customer interactions. Additionally, the workflow software is a tool that is used specifically to lower the collaboration costs in teamwork activities.

Empirically, we can test for the productivity effects of these technologies by entering them as additional terms in the production function. Some results for these technologies are shown in Table II.6. For each technology we present a specification with a linear term representing the technology. Column (1) again shows the earlier result that network technologies are strongly associated with higher productivity. The next two columns then show the separate effects of ERP-CRM and Workflow software technologies – both are weakly positive. In column (4) we include all three of these collaborative technologies in a linear specification. The coefficient for workflow technologies rises but is still not quite significant. Overall, it appears that network technologies dominates as the main type of collaborative technology associated with firm productivity in this sample[42].

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[40] The standard example of this is clerical and desktop tasks. Autor, Levy and Murnane (2003) provide a detailed, representative case study of our ICT displaced clerical tasks in a bank and eliminated a layer of workers within the organisation.

[41] Agrawal and Goldfarb (2008) raise the idea that the collaboration between the two tiers of universities was representative of a division of labour in research with tasks split between high-cost and low-cost sites.

[42] In addition, we tested for complementarities between network equipment and the ERP and workflow tools but found no decisive evidence of positive effects.

D ICT, MANAGEMENT AND ORGANISATIONAL STRUCTURE

Firm level economic competencies represent the final component of intangible capital in the Corrado et al (2006) framework. In their approach, these firm level competencies are grouped into two categories: the first relating to strategic investments designed to support market share (such as advertising, product design or strategic planning) and secondly firm-specific human capital or "structural resources". This second category is broadly defined and hard to measure. It can include both training expenditures and the practices used to organise workers and production processes within the firm. Our exposition below first reviews the theoretical basis of this complementarity; then our approach to measuring firm level economic competencies; and finally an explanation of econometric issues.

(i) Theoretical Framework for Organisation, Management and ICT

It is widely accepted that ICTs facilitate better computation, data management, and communication, changing dramatically the quality and quantity of information available within the firm. This has important implications for firm performance in models where the organisation of the firm is determined by the economics of information and communication.

The leading theoretical explanations of the role of ICT within the firm begin from the perspective of mechanism design, an area of economic theory mainly concerned with the role of information in various decision-making problems. In this class of models (see Marschak, 2004, for a review) firms need to acquire information to make decisions in a changing environment. Decision making authority is delegated to specialists, who operate across the organisation and have access to private information. The firm can decide among alternative mechanisms to assemble the relevant information dispersed across the specialists and use it to make informed decisions, but any of these processes are characterised by non-trivial informational costs. The optimal solution to this problem is the approach that can achieve the best balance between the performance of the mechanism and informational costs. Another feature of this problem relates to the nature of the information-gathering individuals within the organisation. For example, the presence of self-interested individuals may require the introduction of ad-hoc contracts (or implementation schemes), which are able to "revert" their decisions towards firm profit-maximisation.

In this context, ICTs play the crucial role of exogenously lowering the cost of gathering and assembling information within the firm, changing the properties of optimal mechanisms and – as a direct consequence - organisational structure. For example, in Bolton and Dewatripoint (1994) a reduction in communication costs leads to flatter and smaller organisations, although this might not necessarily correspond to a move towards decentralisation. The ultimate effect of ICT on the allocation of decision rights within the firm (i.e. on the emergence of decentralised or centralised organisational settings) is, however, ambiguous once the problems (and thus the information) faced by firm are allowed to differ in terms of complexity, as in Garicano (2000) and Garicano and Rossi-Hansberg (2006). In this setting, organisational structure (hierarchies) arises to optimally organise knowledge within the firm, and workers are allocated to different layers of the organisation according to the type of knowledge they have learned. A higher position in the hierarchy implies knowledge of harder – or less frequent – problems.

In determining at what hierarchical level decisions should be made, firms face a tradeoff between knowledge acquisition costs and communication costs, which are both affected by ICTs. For a given cost of acquiring knowledge, pushing decisions "down" the hierarchy (i.e. decentralisation) imposes a higher cognitive burden on workers at this level. However, centralising all decision-making activities at the Corporate Head Quarter level (i.e. centralisation) increases total communication costs. As a result, the levels at which decisions are taken responds to the cost of acquiring and communicating information. Reductions in the cost of communication allow for a reduction in knowledge acquisition costs through the increasing use of 'management by exception' - local managers will rely more on the corporate head quarters for decision making. Reductions in the cost of information access, on the other hand, reduce the cognitive burden imposed by decentralised decision-making and thus make more decentralisation efficient. Consequently, ICTs affect differently the hierarchical level at which different decisions are taken. Improvements in information technology reducing the cost of accessing information and knowledge, should push decisions "down" whilst improvements in communication technology should push decisions "up", leading to centralisation.

Although the theoretical literature focuses primarily on the complementarity between ICT and organisational structure, which is ultimately modeled as a choice between centralised and decentralised systems, a number of papers have also discussed the interactions between ICT and specific types of management practices. For example, Milgrom and Roberts (1990) describe the rise of "modern manufacturing" techniques, characterised by bundles of organisational and human resource practices. Crucially, this group of activities enters the firm production function in a complementary fashion, i.e. "if the levels of any subset of the activities is increased, then the marginal return to increases in any or all of the remaining activities rises". The main implication of such general concept of complementarity is that exogenous reductions in ICT prices (which affect the cost of collecting, organising and communicating data) generate both direct and indirect effects on the use of the other technologies and managerial practices. For example, reductions in the cost of Computer Aided Design (CAD) machines and software resulted in an increase adoption of this equipment, as well as in the adoption of broader product lines and more frequent product updates. This led to a reduction in delivery times, an increased responsiveness to new orders and quality. From a managerial perspective, the new focus on quality and timely adjustments increased the profitability of team approaches to design and manufacturing engineering, as well as the adoption of pay schemes based on the skills employees acquire (rather than their job assignments) and the delegation of new responsibilities (such as quality checks) to plant level employees.

The adoption of specific types of management practices - especially on the HR side - may also be crucial to make sure that the firm is flexible enough to implement the organisational changes needed to fully reap the benefits of ICTs. For example, Bloom, Sadun and Van Reenen (2008) present a model which focuses explicitly on a narrow set of practices related to *people management*, i.e. practices covering promotions, rewards, hiring and fixing/firing bad performers. The reason for this focus is because of the case study and econometric evidence that effective use of ICT generally requires changing several elements of the way that people are managed. First, there is an abundance of empirical evidence that ICT is on average skill biased and requires shedding less skilled workers, hiring more skilled workers and re-training incumbent workers. In addition to this skill upgrading, ICT-enabled improvements usually require more worker flexibility inside the firm with workers taking on new roles. Secondly, some theoretical work emphasises that when there is uncertainty over how best to use a new technology, giving more discretion to employees with high-powered rewards may be a way to efficiently exploit their private knowledge. Prendergast (2002) emphasised that higher powered incentives (such as output-based remuneration rather than flat-rate salary) may be more common when the principal has uncertainty over what tasks an agent should be performing. Acemoglu et al, (2007) argue that delegation becomes more attractive when there is uncertainty about the best way to use a new technology.

(ii) Measuring Economic Competencies

The theoretical discussion above has identified two main components of firm level economic competencies. These are firstly the bundles of organisational techniques focused on regular production activities (that we call "management practices") and secondly the shape of the hierarchical structures within the firm (which we call "organisational structures" with the usual example being the level of centralisation or decentralisation within the firm).

Our methodology for measuring these two components is based on two key features, which is at the basis of the CEP International Management Survey (IMS). First, the data collection process is uniquely rigorous and therefore highly effective in obtaining accurate measures that are consistent across firms and countries. The key features of this process include the employment of highly-skilled interviewers; the use of "double-blind" techniques to avoid biased or subjective responses; and the full in-house implementation of the survey. We outline this in more detail in Appendix B.

The second part of the methodology relates to questions and topics covered in order to measure management practices and organisational structure. In measuring management practices we used a survey grid of 18 questions relating to key aspects of workplace management. The questions are open rather than tick box and the interviewers are trained to probe with follow up questions in order to ascertain what is actually going on in the firm. Appendix Table A6 gives an example of the questions we used to probe managers and the overall grid. They relate to the promotion system, the fixing/firing of poor performers, the rewarding of high performers and the incentives and importance given to attracting and retaining talented workers. Each question is scored on a scale of 1 ("worst practice") to 5 ("best practice") and our basic composite measure z-scores each individual question, averages across the four questions and then z-scores this average. For example, on the promotion question a low score indicates that employees are promoted solely on the basis of tenure, whereas a high score reflects firms who promote on the basis of effort and ability. The other management practice data we collected related to shopfloor operations (lean manufacturing techniques), monitoring (tracking and reviewing of individual and factory performance) and targets (the breadth, realism and interconnection of goals).

In collecting the measures of organisational structure we asked four questions on plant manager decentralisation. First, we asked how much capital investment a plant manager could undertake without prior authorisation from the corporate headquarters (CHQ). This is a continuous variable enumerated in national currency, which we convert into dollars using PPPs. We also inquired on where decisions were effectively made in three other dimensions: (a) hiring a new full-time permanent shopfloor employee, (b) the introduction of a new product and (c) sales and marketing decisions. These more qualitative variables were scaled this from a score of one, defined as all decisions taken at the corporate headquarters, to a five defined as complete power ("real authority") of the plant manager. In Table A7 we detail the individual questions in the same order as they appeared in the survey, and three anonymised responses per practice. These four questions are similar to others used in the past to measure decentralisation. Acemoglu et al (2007) use a similar question on hiring in the British WERS data. Marin and Verdier (2007) use a count of a series of decentralisation variables scaled 1 to 5. Columbo and Delmastro (2004) have a question similar to our one on investment.

Since the scaling may vary across all these questions, we converted the scores from the four decentralisation questions to z-scores by normalising by practice to mean zero and standard deviation one. In our main econometric specifications, we take the un-weighted average across all four z-scores as our primary measure of overall decentralisation, but we also experiment with other weighting schemes and we also show what happens when the questions are disaggregated into their component parts.

We also asked questions about the plant managers span of control, which is the number of employees he/she directly manage. This is another classic measure of organisational structure in the literature. Finally, we also asked the questions from Bresnahan et al. (2002) on the degree of decentralisation from managers to workers over the pace of work and the allocation of tasks. This provides another measure of decentralisation at a lower level, the manager-worker interaction (rather than at the owner-manager interaction as with our main measure described above).

(iii) Econometric Framework

Empirically, we can study the interaction between ICTs, organisational structure and management practices using the microeconomic production framework that was established earlier in the report. We will denote management practices and organisational structure as elements of overall organisational capital *O*, with complementarities tested in the following production function:

$$y_{ijkt} = \beta^c c_{ijkt} + \beta^k k_{ijkt} + \beta^l l_{ijkt} + \alpha' x_{ijkt} + \beta^o O_{ijkt} + \beta^{co}(c * O)_{ijkt} + u_{ijkt} \qquad (27)$$

where the coefficient β^c gives the direct effect of ICT capital and β^{co} measures the complementary interaction effect with organisational structure. Importantly, the IMS offers a range of different measures of *O* and this allows us to examine specific hypotheses about the link between ICT and organisational capital. For example, in Section III we look at the case of US multinationals in Europe and their deployment of "people management" practices in conjunction with ICT.

Another implication of the idea that ICT capital is complementary with specific types of organisational structure and management is that, ceteris paribus, firms with higher levels of *O* will have a greater demand for ICT capital. Therefore, one can estimate the complementarity using the following equation:

$$O_{ijkt} = \lambda^c c_{ijkt} + \lambda^{w}{}' w_{ijkt} + e_{ijkt} \qquad (28)$$

where w_{ijkt} are controls, e_{ijkt} is an error term (which can be decomposed to include industry and time shocks) and $\lambda^{c\ o}$ is expected to be positive under the hypothesis of complementarity between ICT and *O*.

The combination of AMATECH and the organisational survey also allow the direct estimation of the relationship between organisational structure and different types of ICTs. Namely, we will be able to test the predictions of Garicano (2000), according to which improvements in information technology reducing the cost of accessing information and knowledge should be associated with more decentralisation, whilst improvements in communication technology should lead to centralisation. With this classification in mind, we will estimate equations of the form:

$$O_{ijkt} = \alpha^c comm_{ijkt} + \alpha^k know_{ijkt} + \alpha^{w}{}' w_{ijkt} + e_{ijkt} \qquad (29)$$

where $comm_{ijkt}$ denotes technologies used primarily for communication purposes, and $know_{ijkt}$ denotes technologies primarily used to facilitate knowledge acquisition across different levels within the firm. Using an extension of the Garicano (2000) presented in Bloom, Garicano, Sadun and Van Reenen (2009), we will estimate equation (9) using different types of organisational forms and technologies.

In particular, the model offers predictions over four types of organisational outcomes for which the IMS provides data: the autonomy of the worker, the autonomy of the plant manager, the span of control of the plant manager and the span of control of the CEO. In our estimations, we will denote Enterprise Resource Planning (ERP) systems as technologies that reduce knowledge acquisition costs for managers. This is because ERP systems reduce the cost of acquiring information to solve a problem, and thus we expect them to increase the autonomy of the plant manager. Furthermore, we will denote Computer Assisted Design/Computer Assisted Manufacturing (CAD/CAM) as technologies that significantly reduce the need for production workers to access their superiors for making decisions, and that should thus be associated with more autonomy of production workers. On the other hand, we expect communication technologies to have the opposite impact and centralise decision-making, i.e. we expect it to reduce autonomy of production workers in production decisions and of plant managers on non-production. The key technological innovation that we will use to denote better communication within the firm is the availability of internal networks. More precisely, we will test whether the availability of networks reduced the decision-making autonomy in production decisions of workers and in non-production decisions of managers.

(iv) Empirical Results

Evidence from Production Functions

A key question in analysing firm organisational structures is the impact this could have on firm and national productivity. We implement equation (27) using decentralisation as our measure of organisation and drawing on the data that combined the CEP survey, Harte-Hanks and Amadeus company accounts data across seven European countries. In addition to the factor inputs we include as controls workforce characteristics (the proportion of workers with a degree), firm characteristics (firm age, whether the firm is listed), a complete set of three digit industry dummies and country dummies.

In column (1) of Table II.7 we run a basic specification with only capital, labor and decentralisation, and find a large significant coefficient on decentralisation. The coefficient suggests a one standard deviation increase in decentralisation is associated with a 10% increase in productivity. In column (2) we include the full set of control variables, including the education of the workforce, country and industry controls. In this case the coefficient on decentralisation falls substantially to 0.023 and is now significant at the 10%. This suggests that there is weak *direct* association of decentralisation with higher productivity.

But while decentralisation may only have a small direct association with productivity, it interacts with individual factors of production. To investigate this we need to augment our estimating equation to include interactions with all factor inputs. We do this because of a growing prior literature suggesting that decentralised firms may use information technologies (ICT) more effectively.[43] As discussed above, one rationalisation is that to effectively use new technologies they need local flexibility to experiment. In a decentralised organisation that can be achieved locally, while in a centralised organisation this will have to be enforced from the centre which may be much harder to do. We also include interactions with employment and non-ICT capital because the organisation of the firm may also influence the productivity of these factors.

In column (3) we see the ICT*decentralisation interaction is positive and significant, consistent with this prior literature that ICT is more effectively used in decentralised firms. In column (4) we re-run this estimation including a full set of firm-level fixed effects to control for any other unobserved cross-sectional factors, and again find a positive and significant coefficient (note that the linear time invariant variables are not separately identified from the firm specific effects). In column (5) we add an interaction between decentralisation and non-ICT capital and find a significant negative coefficient, suggesting more traditional non-ICT capital may actually be better utilised in a more centralised firm. Similar experiments with employment and skills interactions with decentralisation were not significant.[44]

The magnitude of the coefficient on the ICT and decentralisation interaction at 0.032 is quantitatively important. The reason is the real ICT capital stock has been growing by about 8% a year faster than non-ICT capital inputs in Europe and the US[45], so that a firm (or country) with

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[43] See, for example, Bresnahan et al (2002) and Bartel, Ichinowski and Shaw (2007).

[44] For example, the point estimate (standard-error) on running a similar regression for employment interacted with decentralisation was 0.0188 (0.0389), and for skills interaction with decentralisation was -0.153 (0.105).

[45] Calculated from 1994 to 2004 using the Groningen Growth and Development Centre dataset for Europe and the US.

one standard-deviation higher decentralisation would have about 0.26 percentage points faster annual productivity growth.

Evidence from Organisational Design Equations

Tables II.8 through II.10 present the main results, each table has a different dependent variable and corresponds to equation (29). We examine decentralisation from the Corporate Head-Quarters (CHQ) to the plant manager in Table II.8, decentralisation to the workers from the plant manager in Table II.9 and the plant manager's span of control (the number of workers he/she directly measures) in Table II.10. Table II.8 contains the empirical results for plant managers' autonomy. All columns control for size (through employment of the firm and the plant), multinational status (foreign multinational or domestic multinational with the base as a purely domestic firm), whether the CEO is located on the same site as the plant manager[46], "noise" controls as discussed in the data section (there are 60 controls including analyst fixed effects) and a full set of country and three digit industry dummies.

Column (1) in Table II.8 uses the presence of Enterprise Resource Planning (ERP) as a measure of information acquisition over non-production decisions. As the theory discussed above predicts, ERP is associated with more autonomy of plant managers (relative to the central head quarters) as the plant manager is allowed greater flexibility in making decisions over investment, hiring, marketing and product introduction. In our model this is because ERP enables him/her to access information more easily and solve more problems without referring them upwards. In terms of the other covariates we find that larger and more complex enterprises (as indicated by size and multinational status) are more likely to decentralise decision-making to the plant manager. Column (2) includes firm level skills, as measured by proportion of employees with college degrees. The variable takes a positive and significant coefficient, indicating that more skilled workplaces tend to be more decentralised (consistent with Caroli and Van Reenen, 2001). This column also includes the PC intensity of plant which enters with a negative and insignificant sign. The ambiguity of the ICT hardware variable should not be surprising as greater computer intensity simultaneously lowers information costs and communication costs which, according to our theoretical model, have opposite effects on autonomy.

The third column of Table II.8 includes an indicator for the presence of networks, which indicates lower communication costs. As the theory predicts, there is a negative coefficient on the network variable (significant at the 5% level) which may reflect the fact that lower communication costs imply that central head quarters make more decisions than the plant manager as it is now easier to pass on solutions. This result is robust to including skills and PC intensity in column (4). Columns (5) and (6) includes both information and communications technologies at the same time. Since these are positively correlated, the results are a little stronger. This table is consistent with the theoretical model sketched earlier: falling information costs are associated with decentralisation, whereas falling communication costs are associated with centralisation.

The next two tables analyse the relationship between communication and information technologies with workers' autonomy and plant manager span of control. Table II.9 is a probit model of workers' autonomy where our indicator of information acquisition over production decisions is CAD/CAM. In columns (1) and (2), the coefficient on CAD/CAM is positive and significant, indicating that such technologies are associated with worker empowerment. In columns (3) and (4), by contrast, the presence of networks has a negative coefficient which is consistent with the theoretical notion that greater communication leads to centralisation.

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[46] All results are robust to dropping size, multinational and CEO-on-site controls. Note that firms where the CEO was the same individual as the plant manager are dropped.

Although the coefficient on NETWORK is correctly signed, it is insignificant even when both technologies are included simultaneously (in the final two columns).

Table II.10 examines the plant manager's span of control as measured by the number of employees who directly report to him. CAD/CAM is associated with significantly greater plant manager span, consistent with the idea that production technologies that help worker information access enable them to do more tasks which makes it possible for the plant manager to oversee more production workers (greater span). The coefficient on NETWORK is positive and insignificant (the theory does not have an unambiguous prediction for this coefficient).

Comparing the empirical results with our theoretical expectations, we obtain a reasonably close match. All the coefficients are in the same direction as the theoretical predictions (when they are unambiguous) and all are significant at the 5% level (with the exception of NETWORK in the worker autonomy equation). The idea that information technologies are associated with increased autonomy and span of control, whereas communications technologies are associated with decreased autonomy appears to have some empirical content. By contrast, the automation story would predict information technologies should be associated with centralisation away from lower level employees and the coordination theories would predict that communication technologies should be associated with decentralisation. Thus, we interpret our evidence on ICT and firm organisation as providing some support for the cognitive view of hierarchies.

Although the estimates are statistically significant and broadly consistent with our theory, are they of economic significance? One way of examining this question is to simulate an increase in the diffusion of our ICT indicators. Given the debate over whether the increasing productivity gap between Europe and the US in the decade since 1995 was related to ICT (e.g. Bloom, Sadun and Van Reenen, 2007), we simulate increasing the ICT diffusion measures by 60% (the difference in the average level of the ICT capital stock per hour worked between the EU and the US 2000-2004

An increase in the penetration rate of ERP of 60% over the sample average of 36% is 22 percentage points. Using the final column of Table II.10, this is associated with a 0.025 of a standard deviation increase in plant manager autonomy. This is equivalent in effect to an increase in the proportion of college graduates by 26% (using the coefficient on education), which is broadly the increase in education achieved by the US between 1990 and 2000 of about a quarter[47].

So we regard this as a substantial effect. Similar calculations show that at the European level increasing the penetration of NETWORK by 60% (21 percentage points at the mean) is associated with a decrease in plant manger's autonomy by 0.023 standard deviations, equivalent to reducing the college share by 24%. This increase in NETWORK is associated with an increase in plant manager's span of 1.1% (equivalent to a 19% increase in the college share) and with a reduction in worker autonomy of -0.005 standard deviations (equivalent to a 10.3% fall in the college share)[48] So the "effect" of falling communication costs (NETWORK) appears somewhat greater for plant manager autonomy than for worker autonomy, with span of control in the middle. Finally, consider a 60% increase in CAD/CAM. This is associated with 0.2% increase in plant manager's span (equivalent to a 3.7% increase in the college share) and a 0.1% increase in worker autonomy (equivalent to a 1.6% increase in the college share). This is lower because the mean of CAD/CAM is lower than the other technologies. This implies that these technical changes appear very important for some aspects of organisation (benchmarked

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[47] In 1990 25.7% of American workers had college degrees or equivalent and this rose to 31.8% by 2004, an increase of 6.1 percentage points or 23.7% (Machin and Van Reenen, 2008).

[48] These calculations use the coefficients in the final columns in Tables 4 and 5.

against equivalent increases in skills), especially ERP on plant manager's autonomy and NETWORK on all three organisational dimensions.

Tables II.8 through II.10 present conditional correlations that seemed to be broadly consistent with the theory. The theoretical model suggests that the endogenous outcomes should covary in systematic ways in equilibrium which is what we examine in the data. We are of course concerned about endogeneity bias as there may be some unobservable that is correlated with the organisational outcomes and our measures of information and communication costs (especially as these are all measured at the firm level). We take some reassurance in the fact that although these ICT indicators are positively correlated in the data[49], their predicted effects on the same organisational variable can take opposite signs. For example, in the plant manager autonomy equation the coefficient on information acquisition technologies (proxied by ERP) is opposite in sign to communication technologies (NETWORK) both theoretically and empirically. For endogeneity to generate these results, the hypothetical unobservable positively correlated with decentralisation would have to mimic this pattern of having a negative covariance with NETWORK and a positive covariance with ERP. This is always a theoretical possibility, but it is not obvious what would generate this bias.

Nevertheless, we do consider an alternative approach to identifying the effects of networks. The cost of electronically communicating over networks differs substantially between countries because of differential degrees of the roll-out of high speed bandwidth and the pricing of telecommunications. Although there have been moves to liberalise the telecommunication sector in most countries, this has happened at very different speeds and in some countries the incumbent state run (or formerly state run) monopolists retain considerable pricing power (e.g. Nicoletti and Scarpetta, 2003; Azmat et al, 2008; OECD, 2005, 2007).

We exploit these differential costs using OECD (2007) series on the prices of leased lines used for networks which represent the cost of an annual subscription to a leased line contract at 2006 PPP US$. An obvious empirical problem is that these measured telecommunication price indices only vary across countries and not within countries, so they are collinear with the country dummies. Industries will be differentially affected by these costs, however, depending on the degree to which they are reliant on networks for exogenous technological reasons. We proxy this reliance by using the intensity of network use in the industry pooling the data across all countries[50]

We then estimate reduced form models. The results for this experiment are presented in Table II.11. The first column simply repeats the baseline specification from column (4) of Table II.8 showing that network presence is associated with centralisation[51]. The second column includes the key variable representing effective network prices. The positive coefficient on this variable is consistent with the idea that higher network costs reduces the use of networking technologies, and so enable plant managers to retain more autonomy. The magnitude of the coefficient suggests that for an industry where 10% of workers use networks doubling communication costs (e.g. moving from Sweden to Poland) decreases autonomy by 0.48 of a standard deviation. A concern is that the country-level network price variable simply proxies some other variable so we include country-level schooling and GDP per person in column (3). The network price variable remains positive and significant in sign

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[49] For example, the pairwise correlation between the ERP and the NETWORK variables is 0.168, significant at the 1% level.

[50] This identification strategy parallels Rajan and Zingales (1998) We also considered specifications where we used network intensive industries defined on US data only and dropped the US from the sample we estimated on. This generated similar results.

[51] Note that the sample is larger because we do not condition on ERP. This could also be endogenous and we have no valid instrument for it. Results are similar if we condition on ERP throughout this table (for example in column (2) the coefficient on the price term is 5.189 with a standard error of 2.221).

From both the production functions and the organisational equations, we see that there is important evidence for complementarity between ICT and organisational firm. The effects of ICT on firm performance are hetereogeneous, and one reason why some firms benefit more than others is that they are better (or worse) organised to take advantage of rapidly falling ICT prices. Decentralisation appears to be one organisational form that is complementary with ICT. Disaggregating the types of ICT is also revealing. Software applications that make it easier for production workers to access information (such as CADCAM) foster worker autonomy. Similarly ERP makes it easier for plant manager's to make informed decisions and so aids decentralisation from the CHQ. By contrast, other types of ICT that just increase communication can actually generate centralising tendencies (such as Networks). The magnitudes of these associations look large – for example increasing the levels of ERP in Europe by 60% (the magnitude of the overall US lead over Europe in ICT capital) has a similar association with manager autonomy as increasing the share of college graduates by 26%. Hence, ICT could have a major impact of employee empowerment and wage inequality through its impact of firm organisation.

E. ICT AND SATISFACTION OF EMPLOYEES

The existing literature on this topic (surveyed in Appendix C, part VI) indicates that the potential effect of ICT use on employee wellbeing and work-life balance is ambiguous. Although the increased mobility awarded by ICT may make it easier to combine work and personal life by, for example, working from home and answering emails on the way to or from the workplace, the pressure of having to be available constantly because the communication technologies in a firm make it possible may have a detrimental effect on an employee's perceived work-life balance and ultimately her satisfaction. To address this question empirically, we conducted a survey as part of a larger project and asked questions on both the use of information technologies as well as the perceived work-life balance along several dimensions. We initially conducted this survey only on German firms. Running an international survey would be beyond the timescale of the current project, but we expect to gain valuable insights from the German example that will come in useful in the future.

We combine three independent datasets covering ICT use; several organisational/strategic characteristics, and firm performance for a sample of German manufacturing firms. We are especially interested in identifying a potential tradeoff between worker wellbeing and financial performance, making it especially important to minimise common respondent (and common method) bias by ensuring that performance, ICT and organisational data come from different sources.

As no information on the organisational structures/HRM practices and learning models of German firms are publicly available, a survey on these topics was conducted. We surveyed only manufacturing firms to focus on a single questionnaire and to avoid problems of interpreting the output of service firms when estimating production functions.

(i) Technology and Work-Life Balance Survey

For this survey, the sampling frame of 600 German manufacturing firms resulted from those firms for which the above mentioned firm performance and ICT information were available. It consisted of those firms for which at least 2004 ICT data and 2004 or 2005 firm performance data were available. These firms formed the sampling frame for a telephone survey which took place in 2008 and was conducted by six student interviewers and two supervising PhD students which were located at a specially equipped telephone studio. The interviewers targeted the firm's switchboards, asking for the production manager or an employee in a similar position. These persons were approached as they typically are in the upper middle of a firm's hierarchy, thus having a good overview of both firm-wide issues like the firm's learning model as well as of more lower-level issues like actual organisational structures and HRM practices. By concentrating on such a narrow set of potential interviewees, measurement error from single informant bias was held relatively constant.

Information on the organisation/HRM practices and learning model were partly gathered with classic verbalised Likert scale questions, and partly by a survey method introduced by Bloom and Van Reenen (2007). This method allows us (1) to get a very detailed insight into the HRM practices of a firm which might not have been possible with a (limited) number of Likert scale questions and (2) to avoid the problem of social desirability which is particularly a problem if asking for HRM practices that support work-life balance.

Some interviewees may for example claim that their firm's frontline personnel have more opportunities to balance their private and working life if asked directly. Instead of asking closed questions, i.e. for example asking interviewees to score a statement about their firm from 1 ("I fully disagree") to 5 ("I fully agree"), interviewees were asked open questions about HRM practices. Their answers were then scored from 1 to 5 by the interviewers. Interviewees did not know that their open answers were scored, ensuring that the problem of social desirability did not occur. The interviews began with an open and quite general question on the decision making process ("How do you make decisions …?") and invited the interviewees to answer freely. To make the interviewees' explanations more concrete, they later asked more detailed questions ("When do you inform your staff …?", "What kind of influence … do your staff members have?"). The interviewers were encouraged to deviate from these prepared questions if needed or suitable and to ask own questions as well as for examples ("Can you describe the last/a typical decision making process for me?") as much as possible. Thus, a conversation led by the interviewer developed for each question which was ended by the interviewer only as soon as he had a full picture of the HRM practice in question and was able to give a score from 1 to 5. Due to this detailed insight into the interviewed firms' HRM practices, even a single item measuring one HRM practice should at least perform as well as a scale from multiple Likert scale items used to measure the same practice. As interviews lasted 45 minutes on average (the maximum interview duration was 78 minutes), an in-depth insight into the firms was given.

The 600 firms from the sampling frame were randomly assigned to the six interviewers in two slices at the beginning and in the middle of the project time. On average, interviewers had to contact a firm eight times to obtain an interview and were able to interview 257 firms successfully, resulting in a response rate of 42.8%[52]. Only 17.5% of the firms explicitly refused to take part in the survey. All other firms have not been contacted during the survey period, were "in queue" at the end of the project[53], did not exist anymore or do not produce in Germany contrary to the information at the time of sampling frame construction. Each interviewer conducted on average 2.7 interviews a day and on average 42.8 interviews throughout the survey period.

A number of questions in the survey relate directly to the use of information technologies to facilitate communication away from the workplace. Specifically, interviewees were asked for the following:

a) Do you have a company notebook? How often do you use it away from your workplace?
b) Do you have a company mobile phone? How often do you use it outside working hours and off-site to talk to colleagues?
c) Can you access your company emails remotely? How often do you do this away from your workplace?

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[52] Response bias does not appear to be an issue if comparing the average size of the interviewed companies (measured in terms of employees, operating revenue and tangible fixed assets) with the average size of the other companies in the sampling frame. This is based on a t-test of group mean differences, assuming equal variances and using conventional significance levels.

[53] As described above, interviewers made about eight firm contacts per interview, i.e. for the firms „in queue" the interviewers were still in the process of trying to make an interview appointment at the end of the project time or had already made an appointment which was then postponed.

d) How often do you organise private matters (e.g. book tickets, private phone calls , arrange social meetings etc.) from your workplace?

Interviewees were also asked for their own perceived work-life balance and the overall work-life balance in the firm as an auxiliary output measure, as well as a number of control variables on the days holiday taken, working hours, and family status. Finally, they were also asked for the existence and extent of use of a number of family-friendly workplace practices. Specifically, these practices were:

a) Financial support for childcare
b) Part-time working
c) Working from home
d) Flexitime

(ii) Combined Dataset

The full dataset comprises information on 259 companies[54] and combines establishment level data on ICT and organisation/HRM practices with company-level data on firm performance. The combined data are valid as (1) establishment level information are extrapolated to create firm level measures, (2) the representativeness of these measures is controlled for and (3) these estimates should be reliable in face of relatively small and thus homogenous companies with on average 3,385 employees in the largest common sample used in the empirical analysis. 53% of the observations in this sample are from firms with a maximum of 500 employees and 78% of the observations from firms with up to of 1,000 employees. Thus, the companies are relatively small in comparison to other studies, where Fortune 1000 firms with on average more than 13,000 employees were analysed (Bresnahan et al., 2002). Second, panel data on firm performance and ICT (1999-2007) area combined with cross-section information on organisation/HRM practices and learning models (2008). Although some measurement error is unavoidable, (1) this is justifiable by the fact that a firm's organisation and HRM practices as well as its learning model are much harder and slower to change than investments in ICT and firm performance, i.e. organisation/HRM practices and learning model can be regarded as quasi-fixed in the short- and middle-term (e.g., Bloom et al., 2007; Bresnahan et al., 2002). (2) Further, a measure for potential changes in organisation, management and learning model is included as a control variable in all analyses. (3) Additionally, the measures of organisation/HRM practices and learning models can at least be interpreted as changes toward the final situation measured in 2008 (Bresnahan et al., 2002).

Estimations and results

We initially ran regressions using both the ICT measures asked directly in the survey and the more general ICT measures from the Harte-Hanks dataset. However, due to the high collinearity between the two measures we focused on the ICT information from our survey which specifically considers flexibility-enhancing ICT:

$$WLB_{jt} = \alpha + \beta_{FLEX} FLEX\_IT_{jt} + \gamma X_{jt}$$

The coefficient β_{FLEX} indicates if the net effect of providing more or less technologies aiding a softening of the boundaries between work and home on perceived work-life-balance is positive or negative. X_{jt} is a set of control variables and demographics of the interviewee. To separate the two effects, we split ICT use up into two variables indicating the use of company-provided

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[54] Two firms that were originally only interviewed for training purposes could be matched with firm performance and ICT data ex-post, leading to a potential sample of 259 firms for the multivariate analysis.

ICT after working hours (IT_AFTER_{jt}) and the private use of company ICT during working hours ($IT\_PRIVATE_{jt}$). Our regression results are reported in Table 1.

Both variables of interest have the expected sign although their significance varies with the sets of control variables included, and working hours play a highly significant (negative) role in the perceived work-life balance of the employee, whereas the option to work flexible hours (Flextime) does not significantly affect work-life balance. Interestingly, the interaction term between Flextime and ICT use after work (ICT_AFTER) is positive, suggesting that employees equipped with the technological means to make use of the flexibility granted to them have higher perceived work-life balance. We also find that the positive correlation of private ICT use during work hours and perceived work-life balance weakens with more intensive use, suggesting decreasing marginal utility or even new role conflicts between private and professional life that arise if too much time at work is taken up dealing with private matters.
We also ran regressions on firm performance (return on assets and return on sales in our specifications[55]) to see if the provision of flexible working arrangements indeed improves firm performance through more motivated staff etc. For this estimation, we use a more general measure of flexibility-enhancing ICT, specifically the share of laptops of all computers in the firm. We also include an interaction term to capture if flexibility only matters if it is supported by the corresponding technology and vice versa:

$$PERFORMANCE_{jt} = \alpha + \beta_{FFWP} FFWP_{jt} + \beta_{FLEX} FLEX\_IT_{jt} + \beta_{FFWP\_IT} FFWP \cdot FLEX\_IT + \gamma X_{jt}$$

Our regression results are reported in Table 2. We find that FFWP carry a positive and significant sign, although that may be down to omitted variables such as management practices (Bloom et al.,2008). Flexible ICT is not significantly correlated with firm performance on its own, but an interaction term with FFWP is significant and positive. This suggests that working arrangements allowing for flexible balancing between work and family life need to be facilitated by the appropriate ICT to realise their potential in improving performance.

In summary, our results point in the expected directions, but their varying levels of significance suggest that further work is in order to establish the robustness and generalisability of the results. The small sample size and the fairly narrow sample of German manufacturing firms may destabilise the results and their significance, but it also seems that many of the fairly strong case study results found in prior literature are artefacts of a carefully selected example rather than an empirical generality to be found in a representative cross-section of the manufacturing sector of a large European economy. We also note that we only used a subset of company ICT, namely the ICT most likely to have an impact on employees' WLB. Thus, while suggestive of a rather intricate influence of information technology on work-life balance, our results are to be interpreted with caution and further research would be called for to identify a robust general relationship between increased ICT use and employee work-life-balance.

SUMMARY OF SECTION II

- Our firm-level work tests for the specific effects of tangible and intangible forms of ICT capital. We find that the intangible capital represented by "own-account" software is strongly associated with firm productivity. Network equipment also seems to be distinct form of tangible ICT capital that has a strong statistical relationship with productivity. Both of these effects are robust to the inclusion of our standard measure of ICT capital and only partially explain our initial baseline coefficient.

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[55] Current measures of labor productivity were not yet available.

- There is minimal evidence of any productivity effects associated with specific types of software, This may be due to “co-invention costs”, that is, the need to support the implementation of software investments with complementary factors. Our empirical work does find a significant complementarity between ICT staff and network hardware in the production function.

- There is only very weak evidence of any complementarities between innovation (as measured by firm patent stocks) and ICT in the production function. ICT’s role in knowledge-intensive activities seems to be better captured as a vehicle for product and process innovation, and we show this in case study of French Autombile retailing. At present, the traditional measures of innovation such as patents are capturing only a subset of formal innovations. ICT is a driver of significant class of product and process innovations and future research should explore this type of link.

- The idea that ICT has facilitated R&D collaboration within and between firms is a popular part of policy discourse. This however is a demanding hypothesis to test. Our regressions linking firm productivity to different hardware and software technologies do indicate that network technologies are strongly associated with higher productivity.

- We study the effect of competitive pressure on the adoption of software innovations in the French car dealer market. The market provides us with an interesting natural experiment because in the middle of our sample, there was a Europe-wide regulatory change that allowed dealers to open outlets in other territories, which was previously restricted by manufacturers.

- In this study of the French car dealer market, we find that scale and product innovations are complements, i.e. larger firms will adopt more product innovations, while product and process innovations are substitute, i.e. firms will adopt one of the two types of innovations. Taken together, these results imply that the introduction of competitive pressure in a market will favor adoption of one type of innovation, but hinder the other.

- We identify a number of relationships between ICT and the organisational features of firms. There is a strong complementarity between decentralization and ICT. Furthermore, certain information applications (specifically CADCAM) are associated with more worker autonomy and ERP packages assist managerial decision-making. Network technologies are actually associated with centralizing tendencies and the effects of ICT are robust to the inclusion of controls for skills measured at the firm level.

- In a study of German firms we find that Work-Life Balance is positively correlated with the use of company ICT for private purposes (i.e. during working hours), but negatively correlated with the use of company ICT after working hours. Hence, the link between employee satisfaction and ICT is determined more by the way ICT is used rather than actual presence of particular technologies.

- Our results suggest a complementary relationship between mobility-focused and flexibility-enhancing ICT and a bundle of family-focused HR practices on firm performance. Thus, Family-Friendly Workplace Practices have to be supported by flexibility-enhancing ICT to reap the highest benefit from them.

III ICT AND GLOBALISATION

Globalisation has been one of the leading topics in international policy debate over the last 10 years. This concern with globalisation has intensified as multinational companies have expanded and import competition from low-wage countries has increased. ICT has been central to this process by lowering communication costs and facilitating the mobility of production. In the sub-Sections below we consider three following major topics linking ICT and globalisation. These topics are (A) the role of technology in multinational business activity; (B) the internationalisation of ICT-intensive industries; and (C) the impact of trade competition on ICT adoption.

A TECHNOLOGY STRUCTURE AND OPERATION OF MNES

Over the past two decades, world inflows of Foreign Direct Investments (FDI) experienced a pattern of impressive growth. In 2007, they reached the new record level of $1,833 billion (an increase of 23% compared to 2006), while the production of multinational enterprises (MNEs) worldwide accounted for 11% of global GDP (UNCTAD, 2008). The diffusion and improvement of ICTs played an important role for the growth of MNEs, improving the ability of firms to fragment their production processes across several countries, and enabling them to amplify the productivity impact of their managerial know-how. In this Section, we illustrate the main theoretical arguments proposed to model the impact of ICTs on the emergence and location of MNEs and on their productivity, and we then propose a simple econometric framework that we plan to use to empirically evaluate these theories.

(i) ICT and Offshoring

In the standard neoclassical framework, the production process is seen as an indivisible bundle of activities, which takes place within specific geographical and institutional boundaries. In order to study the interplay between MNEs and ICT from a theoretical standpoint, however, it is useful to introduce the notion of a production process that can de decomposed into smaller set of activities, which can be a) performed within the boundaries of the firm, or outsourced to other firms; and b) performed in the same country where the headquarters of the firms are located, or in different countries. In this setting, FDI arises when the firm decides to shift part of its production activities abroad, while keeping them within the boundaries of the firm.

Improvements in communication technologies appear to play a key role for the decision to engage in FDI activities[56]. This is because better communication weakens the link between labor specialisation and geographic concentration, making it increasingly viable to separate the production process in time and space and thus reducing the costs associated with the "unbundling" of the different stages of production. For example, the Internet allows instantaneous transmission of information and documents, and technologies such as mobile phones and teleconferencing are at least to some extent able to substitute face-to-face contacts between managers and employees. This reduces the costs associated with FDI - or more generally, with offshoring - especially for production processes which are not entirely codifiable and rely on "soft" managerial skills.

A recent model that considers explicitly the role of ICT in facilitating the decision to offshore part of the production abroad is provided by Grossman and Rossi-Hansberg (2008). In this model,

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[56] More generally, ICTs play a key role for the offshoring decision, i.e. the decision to locate part of the production process abroad either within the boundaries of the firm, or through unaffiliated suppliers. The latter option is defined as outsourcing.

production requires a continuum of *tasks* from each factor of production. In the basic set up the two factors of production is skilled and unskilled labour. All tasks need to be performed to produce the final good, and each task can be performed at home or abroad. Factor costs are allowed to differ across countries, and the decision to do the task abroad involves an extra cost - which is task specific. For example, some tasks like back office operations are naturally easier to offshore, compared to others that are intrinsically local, such as transportation services. Improvements in information technologies translate directly into lower costs of offshoring all tasks performed by low-skilled labor. One of the key implications of this model is that improvements in information technologies have the same effects of factor-augmenting technological change in low-skilled labor, instead of Hicks neutral technological change. In other words, a reduction in offshoring costs leads to generalised productivity improvements for all factors of production, both low and high skilled workers. In particular, even the low-skilled workers in the skill abundant country enjoy a productivity effect, which is reflected in their wages[57].

A different take on the role of ICT for offshoring decisions (including FDI) is presented in Antras, Garicano and Rossi-Hansberg (2006). In this model, offshoring is modeled as the formation of cross-country teams of production. In the basic set up, there is a continuum of agents with different abilities, forming production teams in which there is one manager and several workers. Managers are essentially problem solvers (i.e. they engage in knowledge intensive activities), and workers deal mostly with routine tasks. Manager and worker ability are complementary, i.e. better managers are able to manage more workers, and better workers allow managers to form larger production teams. This feature of the model determines assortative matching in team formation (where better managers will tend to form teams with better workers) and, ultimately, the occupational choice of agents. The cost of communication technology plays a crucial role in this setting, since it allows managers to have larger teams, increasing team productivity. To study the implications of this production technology for globalisation, the model is extended to a one-sector, two-country (North and South) framework. The main difference between the two countries is in the skill distribution, which has a lower mean in the South. The model leads naturally to offshoring – that is, the formation of international teams - where northern managers supervise teams of southern workers. Once more, the cost of communication technology is key. First, lower communication costs allow northern managers to deal with larger teams, thus increasing the number of workers worldwide, increasing the number of managers in the North and reducing the number of managers in the South in equilibrium. Second, lower communication costs increase the quantity of offshoring activities (defined as the proportion of southern workers working for northern managers), but it reduces its quality (defined as the average skill level of workers that form international teams relative to the skill level of all southern workers)[58].

The model is extended in Antras, Garicano and Rossi-Hansberg (2008) to a setting with multi-layered production teams. In this setting, middle managers can be used to improve the efficiency of the transmission of knowledge across countries. The model thus predicts that the availability of “middle skills” (i.e. individuals who could potentially serve the role of middle managers) is crucial in attracting offshoring in situations where an efficient organisation of production requires middle managers. However, the effect of middle skills availability is reduced if the communication technologies available in the South are sufficiently developed. This is because efficient communication technologies foster the creation of local (i.e. fully southern)

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[57] However, note that the ultimate effect on the wages of skilled workers in the skill abundant country is ultimately uncertain. This is because the reduction in offshoring costs generates a *relative price effect* – i.e. if the prices of the low-skill intensive good falls thanks to the productivity effect, this will exert downward pressure on the low-skill wage - and a *labor-supply effect* – i.e. if more low-skilled jobs are offshored, this frees up domestic low-skill labor that needs to be reabsorbed into the labor market.

[58] The model also provides a rich set of implications for wage inequality. Namely, globalisation leads to higher wage inequality in the South (since better workers in the South benefit with the match with better managers in the North), and to higher wage inequality in the North if the cost of communication technologies is low enough to increase considerably the span of control of managers.

teams, increasing the opportunity cost (and thus, the equilibrium remuneration) of southern middle managers.

In summary, the models we just discussed predict a strong relationship between decreases in the costs of technologies that facilitate communication across countries, and increases in offshoring activities – including FDI. In absence of a valid instrument, we are not able to directly test whether ICT directly *causes* the expansion of MNEs. Instead, we are able to observe how individual multinationals allocate their high-tech and low-tech tasks across countries. The ownership data within the AMADEUS and ORBIS databases provides unique information on the international distribution of MNE activities, both in terms of the countries where subsidiaries operate and the industries involved. Importantly, this represents a new range of descriptive statistics for summarising the global activity of firms. In particular, it is possible to rank 4-digit industries by their technology usage and then examine how global MNEs distribute their activity across countries. The AMATECH data is useful for this purpose as it offers over one million observations for pooling and ranking the technology intensity of SIC4 industries. In the following work we have therefore constructed a "technology ladder" of industries where each industry has been ranked according to its PC intensity. This is a very effective tool for ranking industries insofar that it has a high coverage of industries and also provides a continuous measure of technological intensity. By contrast, other potential measures of technological intensity are either selective in the industries they cover (eg: R&D and patents are mainly found in manufacturing) or do not directly measure technology (eg: physical capital or skills).

A basic but revealing look into the international division of activities can be obtained by looking at the relationship between subsidiary industry activities and ultimate owners within the ORBIS database. Some information is reported in Tables III.1 and III.2. These tables are based on a sample of the largest 100 MNEs in the US, Europe and Japan on the basis of recent turnover. This group of the largest 100 MNEs have approximately 21,000 subsidiaries between across all countries in the ORBIS world database. Note here that an important feature of the ORBIS data is that it reports multiple primary and secondary industry codes, in other words, a range of SIC4 activities in which a given firm is active. Table III.1 shows that when the MNE's SIC4 activities are accumulated (ie: when the subsidiaries are taken as a conglomerated unit headed by the ultimate owner) their scope is revealed as highly diverse. The Top 100 MNEs operate across an average of approximately 150-170 distinct SIC4 industries and 35-44 SIC2 industries.

Our analysis is based on a sample of MNE "ultimate owners" and their subsidiaries. The main econometric tool for studying these relationships is an equation that characterises given subsidiary-SIC4 unit or "task" as either low or high tech:

$$\Pr(LOWTECH)_{ijkt} = \lambda^1 SUBS_{ijkt} + \lambda^2{}' ULT_{ijkt} + e_{ijkt} \qquad (33)$$

where *Pr(LOWTECH=1)* is defined for those industries that fall into the bottom two quintiles of our PC-based technology ladder. The SUBS term represents a vector of subsidiary characteristics (principally the country location) while ULT is a vector of ultimate-owner characteristics (such as home nationality or size).

Table III.2 reports the results of estimating equation (33) using this sample of subsidiary activities in manufacturing. The first column estimates the probability that a given subsidiary-activity is low-tech based on the characteristics of the subsidiary or ultimate-owner. The first column shows two immediate findings – a task is more likely to be characterised as low-tech if the subsidiary is located in China and less likely if the subsidiary is located in the ultimate-owner's originating country. This confirms the basic intuition of comparative advantage – low-tech manufacturing is taken off-shore to low wage countries while more advanced tasks are kept close to the firm's core or home country. The second column adds some firm size controls while the third column controls for the ultimate-owners SIC2 industry. More strikingly, the final column controls for ultimate-owner fixed effects, allowing us to compare the probability of being low-tech amongst subsidiaries on a *within-firm* basis. The China subsidiary effect is resilient to this control, indicating that subsidiaries located there are 11% more likely to be undertaking low-tech tasks.

(ii) ICT and the Productivity Advantage of MNEs

The models discussed in the previous section argue that ICT has a direct effect on the creation of new offshoring opportunities, but they do not distinguish between increases in FDI (i.e. in the creation of new multinational subsidiaries), or expansion of arm length's activities (licensing or subcontracting). Recent contributions, however, point to the fact that the role of ICT might be particularly important for the everyday activity and the productivity of multinational firms. This is because MNEs tend to show very specific managerial and organisational characteristics compared to other firms in their home country, which they tend to transplant across their subsidiaries. To the extent that some of these characteristics are complementary with ICT, this implies that MNE subsidiaries might be able to enjoy higher returns from their ICT investments independently from their location. In this Section we illustrate the basic theoretical arguments behind this concept.

A recent strand of the trade literature has documented the fact that a systematic relationship exists between firm characteristics and the participation in foreign trade and investment. One of the stylised facts emerging from these studies is that exporting firms and firms engaging in FDI activities are not a random sample of the population of firms. On the contrary, exporting firms appear to be systematically more productive than purely domestic companies, and MNEs are, in turn, more productive than simple exporters. In a series of seminal papers, Melitz (2003) and Helpman, Melitz and Yeaple (2004), provide a simple theoretical framework to rationalise these findings. A key feature of the Melitz (2003) model is to explicitly consider the interactions between heterogeneous firms and fixed exporting costs. In particular, the decision to export to a foreign country involves a fixed sunk cost – which proxies for distribution and servicing costs – that the firm has to bear in every country in which it decides to export. In this setting, a sorting pattern emerges where exporting firms are more productive than non-exporters and are bigger. In Helpman, Melitz and Yeaple (2004) this logic is expanded to examine the decision to engage in FDI activities. In choosing between exporting and setting up a multinational in a country, a firm faces a proximity-concentration trade-off, i.e. by choosing FDI the firm gives up the benefits that might arise from the concentration of production (thus incurring higher fixed costs), but it saves on variable costs by avoiding trade costs. Once more, the setting delivers a clear sorting of firms, that is consistent with the empirical evidence, i.e. multinational corporations are more productive than exporters that are not multinationals, and exporters who are not multinationals are more productive than purely domestic firms.

Although Helpman, Melitz and Yeaple (2004) rationalise the productivity advantage of MNEs, they remain silent on the precise nature of what makes MNE subsidiaries "special" compared to other firms, as well and on the mechanism through which MNEs are able to transplant their productivity advantage across their subsidiaries. A recent paper by Burstein and Monje-Naranjo (2007) provides a theoretical discussion of both these points. Using an extension of the Lucas (1978) model of occupational choice, they investigate the effect of reallocating firm management know-how across countries. In this setting, MNEs are characterised by a common level of productivity, which enters as an additional factor of production in combination with local workers. The model is used to explore from a quantitative point of view the welfare consequences of FDI. The key finding is that eliminating FDI would results in very large negative welfare effects, even with no spillovers on local firms and with source countries appropriating the marginal contribution of their managerial know-how.[59]

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[59] Note that in Burstein and Monje-Naranjo (2008) the MNE productivity advantage is common across subsidiaries by assumption. However, this can be endogenised using the models of international team formation by Antras, Garicano and Rossi-Hansberg (2006) discussed in the previous section.

However, the fact that MNEs enjoy a productivity advantage (or, using the terminology of Burstein and Monje-Naranjo, a special "managerial know-how"), and that this is transplanted across the subsidiaries independently on their location, does not automatically imply that MNEs will enjoy higher returns from their ICT investments. In order for this to happen, the managerial characteristics adopted by MNE firms need to be in a complementary relationship with ICT. Bloom, Sadun and Van Reenen (2008) present a model where the presence of these complementary organisational and managerial practices across the subsidiaries depends on the adoption costs in the country where the MNE is headquartered. The model thus predicts that differences in ICT returns across countries will be mirrored by their MNE subsidiaries, independently from their location.

The International Management Survey (IMS) data discussed in Section II provides a number of opportunities to test these hypotheses. The most obvious is firstly descriptive statistics on organisational capital and ICT capital across domestic firms and multinationals. The econometric approach to testing these theories then follows the production function approach of earlier Sections with new heterogeneity terms:

$$y_{ijkt} = \beta^{c} c_{ijkt} + \beta^{k} k_{ijkt} + \beta^{l} l_{ijkt} + \alpha' x_{ijkt} + \beta^{mne} MNE_{ijkt} + \beta^{cmne} (c * MNE)_{ijkt} + u_{ijkt} \qquad (34)$$

where an MNE dummy has been included as both a linear and interaction term with ICT capital. This basic equation can be expanded in a number of ways. The most straightforward modification is to split the MNE variable out by nationality, for example by US and non-US multinationals. The specific testing of theories such as those by Burstein and Monje-Naranjo (2008) then involves the addition of variables representing organisational capital (in particular, management practices). The key issue for testing here is whether the interaction between organisational capital and ICT accounts for the MNE*ICT interaction. If we see a reduction in the β^{CMNE} coefficient as a result of adding this further interaction then this indicates that organisational capital is driving some part of the overall MNE productivity and technology advantage.

(iii) Empirical Results

The first dataset we use is an original UK establishment level panel constructed from combining multiple datasets within the UK Census Bureau. The basis of the UK data is a panel of establishments covering all sectors of the UK private sector called the Annual Business Inquiry (ABI). It does not include financial services, which is a virtue given the difficulty of measuring productivity in these sectors as the credit crunch has amply demonstrated. It is similar in structure and content to the US Longitudinal Research Database (LRD), which contains detailed information on revenues, investment, employment and material/intermediate inputs. However, unlike the US LRD it also covers the non-manufacturing sector from the mid-1990s onwards. This is important, because the majority of the sectors responsible for the US productivity acceleration are outside manufacturing, such as retailing and wholesaling[60]. We were also able to obtain access to several surveys of establishment-level ICT expenditure conducted annually by the UK Census Bureau, which we then matched into the ABI using the establishment's reference number. The dataset is unique in containing such a large sample of establishment-level longitudinal information on ICT and productivity.

We build ICT capital stocks from ICT expenditure flows using the perpetual inventory method and following Jorgenson (2001), keeping to US assumptions about depreciation rates and hedonic prices. We considered several experiments by changing our assumptions concerning the construction of the ICT capital stock using alternative assumptions over depreciation rates

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[60] The new US Longitudinal Business Database includes services but does not have information on ICT or non-ICT investment (see Davis et al, 2006).

and initial conditions[61]. Furthermore, we present results using an entirely different measure of ICT usage based on the number of workers in the establishment who use computers (taken from a different survey, the E-Commerce Survey). Qualitatively similar results were obtained from all methods.

Our final dataset runs from 1995 through 2003, but there are many more observations after 1999. After cleaning, we are left with 21,746 observations with positive values for all the factor inputs. Note that the panel is unbalanced: we keep all entrants and exiting firms. The results are robust to conditioning on three continuous time series observations per firms, but are weaker if we start conditioning on many more observations as we induce increasing amounts of selection bias.

There are many small and medium-sized establishments in our sample - the median establishment employs 238 workers. Average ICT capital is about 1% of gross output at the unweighted mean (1.5% if weighted by size) or 2.5% of value added. These estimates are similar to the UK economy-wide means in Basu et al (2003).

There are large numbers of multinational establishments in the sample. Ownership is identified using the Annual Foreign Direct Investment registry (which tracks ownership in the UK Census data), which we also use to identify takeovers (from changes in ownership). About 8% of the establishments are US owned, 31% are owned by non-US multinationals and 61% are purely domestic. Multinationals' share of employment is even higher and their share of output higher still. Table III.3 presents some descriptive statistics for the different types of ownership, all relative to the three-digit industry average. Labor productivity, as measured by output per employee, is 24% higher for US multinational establishments and 15% higher for non-US multinational establishments. This suggests a nine percentage point productivity premium for US establishments as compared to other multinationals. But US establishments also look systematically larger and more intensive in their non-labor input usage than other multinationals. US establishments have 14 percentage points more employees, use about 8 percentage points more intermediate inputs per employee and 10 percentage points more non-ICT capital per employee than other multinationals. Most interesting for our purposes, though, the largest gap in factor intensity is for ICT: US establishments are 32 percentage points more ICT intensive than other multinationals. Hence, establishments owned by US multinationals are notably more ICT-intensive than other multinationals in the same industry.

Results from the UK Establishment Panel

Basic Results - In Table III.4 we examine the output elasticity of ICT in the standard production function framework described in Section II (these are all different implementations of equation (4)). Column (1) estimates the basic production function, including dummy variables for whether or not the plant is owned by a US multinational ("USA") or a non-US multinational ("MNE") with domestic establishments being the omitted base. US establishments are 7.1% more productive than UK domestic establishments and non-US multinationals are 3.9% more productive. This 3.2% (= 0.0712 - 0.0392) difference between the US and non-US multinationals coefficients is also significant at the 5% level (p-value = 0.02) as reported at the base of the column[62].

The second column of Table III.4 includes the ICT capital measure. This enters positively and significantly and reduces the coefficients on the ownership dummies. US establishments are more ICT intensive than other establishments, but this only accounts for about 0.2 percentage

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[61] First, because there is uncertainty over the exact depreciation rate for ICT capital, we experimented with a number of alternative values. Second, we do not know the initial ICT capital stock for ongoing establishments the first time they enter the sample. Our baseline method is to impute the initial year's ICT stock using as a weight the establishment's observed ICT investment relative to the industry ICT investment. An alternative is to assume that the plant's share of the industry ICT stock is the same as its share of employment in the industry.

[62] This implies that about two-thirds (6 percentage points of the 9 percentage point gap) of the observed labor productivity gap between US and other multinationals shown in Table 1 can be accounted for by our observables, such as greater non-ICT capital intensity in the US establishments, but a significant gap remains.

points of the initial 3.2% productivity gap between US and non-US multinational establishments. Column (3) includes two interaction terms: one between ICT capital and the US multinational dummy and the other between ICT capital and the non-US multinational dummy. These turn out to be very revealing. The interaction between the US dummy and ICT capital is positive and significant at conventional levels. According to column (3) doubling the ICT stock is associated with an increase in productivity of 6.3% (=0.0428 + 0.0202) for a US multinational but only 4.6% (=0.0428 + 0.0036) for a non-US multinational. Note that non-US multinationals are not significantly different from domestic UK establishments in this respect: we cannot reject the possibility that the coefficients on ICT are equal for domestic UK establishments and non-US multinationals. It is the US establishments that are distinctly different. The reported *US*ln(C/L)* interaction tests for significant differences in the output-ICT elasticity between US multinationals and UK domestic establishments. The key test, however, is whether the ICT coefficient for US multinationals is significantly different from the ICT coefficient for other multinationals. The row at the bottom of Table III.5 reports the p-value of tests on the equality between the *US*ln(C/L)* and the *MNE*ln(C/L)* coefficient (i.e. Ho: $\alpha^{C,USA} = \alpha^{C,MNE}$), showing that the coefficients are significantly different at the 5% level.

To investigate the industries that appear to account for the majority of the productivity acceleration in the US we split the sample into “ICT using intensive sectors” in column (4) and “Other sectors” in column (5). Sectors that use ICT intensively account for most of the US productivity growth between 1995 and 2003. These include retail, wholesale, business services and hi-tech manufacturing like printing/publishing. The US interaction with ICT capital is much stronger in the ICT-using sectors, and it is not significantly different from zero in the other sectors (even though we have twice as many observations in those industries). The final three columns include a full set of establishment fixed effects. The earlier pattern of results is repeated; in particular, column (7) demonstrates that US establishments appear to have a significantly higher coefficient on their ICT capital stocks than other multinationals (and domestic firms)[63]. A doubling of the ICT capital stock is associated with 1.2% higher productivity for a domestic or non-US multinational, but 4.9% higher productivity for an establishment owned by a US multinational.

Quantification – The magnitude of the results are extremely large – they appear to suggest that better US management could explain about 50% of its superior ICT related growth over the 1995 to 2004 decade. To explain this we start with the results in column (7) of Table III.4, that report a US coefficient on ICT capital stock that is about 3.7% higher than for domestic firms or non-US multinationals. Given that ICT intensity over the period of 1995 to 2004 was rising at about 22% per year in both the US and EU (Timmer and Van Ark, 2005), this implies a faster growth rate of labor productivity of US establishment in the ICT intensive sector of about 0.81 percentage points per year (=0.22×3.7%). ICT intensive industries account for about half of aggregate employment so that this higher coefficient – if applied to the US economy – would imply that aggregate US labor productivity would rise at about 0.4% a year faster than in Europe (= 0.5×0.81) between 1995 and 2004. Since actual US labor productivity growth over this period was at least 0.8% higher than in Europe, this coefficient would suggest that about half of the US productivity miracle was related to the stronger relationship between productivity and ICT in the US than Europe.

US multinational Takeovers - One concern with our empirical strategy is that US firms may “cherry pick” the best UK establishments. In other words, it is not the US multinational’s management that generates a higher ICT coefficient but rather that American firms systematically take over UK establishments with higher output-ICT elasticities. To look at this issue, we examined the sub-sample of establishments that were, at some point in our sample

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[63] We were also concerned that the ICT interaction could be driven by the presence of labor in the denominator of both the dependent variable and the interaction so we re-estimated without normalising any of the variables by labor. The US interaction with ICT was still significantly different from the non-US multinational interaction with ICT (p-value = 0.040).

period, taken over by another firm in the ICT-intensive sectors. We considered both US and non-US acquirers[64].

Note that the identification assumption here is not that establishments that are taken over are the same as establishments that are not taken over. We condition on a sample of establishments who are all taken over at some point in the sample period. Thus, we assume that US multinationals are not systematically taking over establishments that are more productive in their use of ICT than non-US multinationals. We can empirically test this assumption by examining the characteristics - such as the ICT level, ICT growth and ICT productivity - of establishments who will be taken over by US multinationals in the pre-takeover period relative to non-US multinationals. We will show that there is no evidence of such positive selection[65].

In column (1) of Table III.5, we start by estimating our standard production functions, for all establishments that are eventually taken over in their *pre-takeover* years (this is labelled "before takeover"). The coefficients on the observable factor inputs are similar to those for the whole sample in column (2) of Table III.4. Unlike the full sample, though, the US and non-US ownership dummies are insignificant, suggesting that the establishments taken over by multinationals are not *ex ante* more productive than those acquired by domestic UK firms.

In column (2) of Table III.5 we interact the ICT capital stock with a US and a non-US multinational ownership dummy, again estimated on the *pre-takeover* data. We see that neither interaction is significant – that is *before* establishments are taken over by US firms they do not have unusually high ICT coefficients. So, US firms also do not appear to be selecting establishments that already provide higher ICT productivity. In column (3) we estimate production function specifications identical to columns (1) but on the *post-takeover* sample. The US multinational ownership coefficient has moved from being negative in the pre-takeover period to being positive, implying a change of 10.1%. By contrast the non-US multinational coefficient hardly changes (it actually falls by 2%).

Column (4) is the post-takeover version of column (2) where we allow the coefficient on ICT to differ by ownership status. As in the earlier results of Table III.4, the interaction between ICT and US ownership is positive and significant at the 5% level (and is significantly different than the non-US multinational's ICT coefficient at the 10% level). The test of the difference of the *US*ln(C/L)* interaction before and after the takeover is significant at the 10% level (p-value=0.097)[66].

The fifth column of Table III.5 breaks down the post takeover period into the first year after the takeover and the subsequent years[67]. The greater productivity of ICT capital in establishments taken over by US multinationals is revealed only two and three years after takeover (this

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[64] We have a larger number of observations "post-takeover" than "pre-takeover" as there was a takeover wave at the beginning of our sample in the late 1990s associated with the stock market bubble and high tech boom. For these establishments, we necessarily have a lot more post takeover information than pre-takeover information. We drop takeovers which resulted in no change of ownership status (e.g. a US multinational taking over another US multinational subsidiary – see Appendix A).

[65] If US multinationals have higher ICT productivity why do we not observe some systematic selection of US firms taking over particular UK establishments? We show there is some weak evidence of negative selection which is consistent with a simple model (discussed below and in Appendix B) of international transfer of management practices with a fixed costs. It is likely this incentive is small in magnitude compared to the many other causes of international merger and acquisitions. Statistically, the only variable which was significant in a takeover model was size: US multinationals were more likely to take over larger plants than non-US multinationals. ICT and other factors were insignificant.

[66] We examined whether the US productivity advantage was because they were more aggressive at closing down less efficient establishments. Foster, Haltiwanger and Krizan (2006), show that almost all aggregate US retail labor productivity growth in their sample is through this type of restructuring. In our data, although multinationals did close down more establishments post-takeover than domestic takeovers, American firms did not seem to do this significantly more than other multinationals.

[67] Note that throughout the table we drop the takeover year itself as we cannot determine the exact timing within the year when the takeover occurred.

interaction is significant at the 5% level whereas the interaction in the first year is insignificant). This is consistent with the idea that US firms take some time to reorganise before obtaining higher productivity gains from ICT. Domestic and other multinationals again reveal no pattern, with all the dummies and interactions remaining insignificant.

The sample in Table III.5 includes some multinational firms that are taken over by domestic UK firms, so a stronger test is to drop these observations and consider only takeovers by multinational firms. In column (6) we replicate the specification of column (5) for this smaller sample and again find that establishments taken over by US multinationals have a significantly higher coefficient on ICT capital after two or more years than non-multinational takeovers.

Although there is no evidence that US firms are "cherry picking" the better UK establishments, it is noticeable that the point estimates in column (1) and (2) are consistent with the idea that US firms may select the UK establishments that have *lower* ICT coefficients in the production function, a form of negative selection. Although these point estimates are statistically insignificant, negative selection is consistent with a model where US firms are able to transfer their management practices to the plants they acquire. If this transfer has an element of fixed disruption cost, US firms will have a greater incentive to reorganise firms after takeover and so will be more willing to purchase badly managed firms that they can "turnaround". This has the interesting implication that allowing US multinationals to undertake extensive take-overs across Europe will be particularly helpful for increasing ICT linked productivity growth. The reason is the US multinationals are potentially picking off and improving the worse performing firms, substantially improving the average level of ICT productivity.

Firm-level Panel data from seven European countries
A disadvantage of the UK establishment level panel is that it does not contain direct information on management practices. To remedy this we use a second panel dataset across seven European countries that combined three main sources: the Center for Economic Performance (CEP) management survey, the Harte-Hanks ICT panel and the Amadeus database of firm accounts (As discussed above). The results so far suggest that US owned establishments have a higher elasticity of productivity with respect to ICT intensity, even after taking over existing establishments. This implies there may be an unobserved factor that is more abundant in American firms and that is complementary with ICT. In this section we explore the idea that people management practices constitute this previously unobserved factor and use our survey instrument to measure it. In the first sub-section we discuss some descriptive statistics and in the second sub-section we offer some econometric results consistent with our key hypothesis.

Before we present the results it is worth considering some supporting evidence on the different internal management of American firms compared to those in Europe and Asia. Remember that we choose these people management aspects because the econometric and case-study evidence suggest that these features of the firm are particularly important for effectively using ICT, which frequently requires substantial changes in the way that employees work.

If we look at the people management scores of 4,003 firms in the US, Asia and Europe we see that firms based in the US have much higher scores than firms in other countries – about half a standard deviation on average (see Figure [3a and 3b]). In If we examine a sub-sample of the data looking at management scores of subsidiaries located in our seven European countries by multinational origin there is a similar pattern[68]. Interestingly, the affiliates of US multinationals in Europe tend to have much higher people management scores than other countries. This is consistent with the idea that US firms are able to transfer some of their practices overseas to their subsidiary operations[69]. Local labor market regulations influence people management

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[68] A multinational source country had to have at least 25 subsidiaries in the sample to be included in the graph.

[69] The high people management ratings for some countries such as Germany may appear surprising given their high degree of labor market regulation. This arises because the average scores for management practices as a whole in Germany are high (although relatively stronger in operations). Bloom and Van Reenen (2007) relate this to a combination of relatively high skill levels and few primo geniture family firms.

practices, but do not completely determine them. If they did, there would be no systematic difference in the management practices of US subsidiaries in Europe compared to other firms.

Table III.6 contains the results from the European panel. In columns (1) to (7) we estimate the production function and in the final two columns the ICT intensity equation. Column (1) estimates a basic productivity equation controlling only for capital, labor, ownership status and some basic controls (country dummies interacted with time dummies, three digit industry dummies and listing status). As with the UK establishment data, US multinational subsidiaries have higher measured total factor productivity than other multinationals (and domestic firms). As before, the data is consistent with constant returns to scale (i.e. the coefficient on labor is insignificant). The point estimates are much larger than for the establishment level data because materials is not included as an explanatory variable as this is not available in most company accounts. If materials are included the point estimates on the sub-sample look very similar to those for the establishment level data[70].

The second column of Table III.6 uses the sub-sample of the data where we observe ICT (i.e. the sample that overlaps with the H-H dataset). First we follow Table III.4 and simply interact the ownership dummies with the ICT measure. Exactly as we saw in the UK establishment panel the coefficient on ICT is significantly higher for US multinationals compared to non-US multinationals (and also to domestic firms). Column (3) replaces the multinational interactions with ICT with our measures of people management practices and their interaction with ICT intensity. As the model predicts, there is a positive and significant interaction between people management and ICT intensity. Column (4) is the key column which includes both sets of interactions. We find that conditional on the management interactions, the coefficient on the interaction of ICT and US ownership has dropped by more than half in magnitude and is now insignificantly different from zero. This is a key result: it suggests that the reason that we observed a higher coefficient on ICT for US multinationals in column (2) was because: (i) they have higher levels of people management and (ii) there is a complementarity between ICT and people management[71].

Column (5) of Table III.6 repeats the specification from column (4) but now includes a full set of firm fixed effects. The pattern is broadly the same, although the precision of the estimates has fallen, as would be expected when we rely solely on within-firm variation[72]. The interaction between ICT and people management remains significant at the 10% level, whereas the coefficient on the interaction between ICT and US ownership is now only 0.019 and completely insignificant. In the management survey we also collected information of the proportion of the workforce who held college degrees. In all of the regressions this has a positive and significant association with productivity, as we would expect from basic human capital theory.

The final two columns of Table III.6 present the regressions where ICT intensity is the dependent variable. Column (7) shows that US firms are much more ICT intensive than other multinationals and domestic firms. The people management variable also has a strong and positive correlation with ICT intensity as shown in column (8). In this final column the US coefficient falls from 0.260 to 0.215, indicating that part of the higher ICT intensity in US multinationals is due to the higher levels of people management.

There is a large literature showing that new technologies are complementary with skills (e.g. Autor, Katz and Krueger, 1998). If US firms have higher levels of skills, could this simply explain

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[70] For example, including materials in column (1) specification reduces the sample size to 3,403 observations, delivering point estimates (standard-errors) on capital, US and non-US multinational ownership, and materials of 0.1110 (0.0154), 0.1419 (0.0490), 0.0485 (0.0256) and 0.5214 (0.0267) respectively. If computers are included, the point estimate (standard error) is 0.0435 (0.0174).

[71] If we drop the interactions and ownership variable, the people management score in levels is positively and significantly related to productivity at the 10% level: a coefficient of 0.028 with a standard error of 0.016.

[72] Note that the management and ownership status variables are cross sectional so the linear terms are absorbed by the fixed effects, even though their interaction with ICT is still identified.

our results? Fortunately, the CEP management survey contained a measure of the proportion of employees with college degrees. We include this variable throughout Table III.6 and find it to be consistently positive in the production function. In column (6) we also include the interaction of this human capital measure with ICT. The ICT*skills interaction enters with a positive but insignificant coefficient, but the management interaction with ICT remains robust to this extra interaction.

We checked for a large number of other confounding factors that could be correlated with management practices and be driving the results on the interaction with ICT. These included average hours worked, union strength, different types of software (e.g. Enterprise Resource Planning). Although these were systematically different in European and US firms, they did not change the ICT and management results.

So in summary, the evidence from the European panel has the same basic pattern of results we saw in the UK establishment panel. US firms appear to have some advantage in ICT. The new piece of information is that this advantage appears to be linked with their superior people management practices that are complementary with ICT and this explains, at least in an accounting sense, the higher coefficient on ICT for US firms observed in the earlier tables. This quantification of this effect suggests that these US style management practices can account for around 50% of the differential impact of ICT on productivity, and are a major factor in why Europe did not have the ICT productivity miracle from 1995-2004 which the US enjoyed.

B PERFORMANCE AND INTERNATIONALISATION OF ICT INTENSIVE SECTORS

The importance of the ICT-intensive sectors in driving productivity growth has been well-documented (e.g. Jorgensen et al 2008). Although sectors that intensively produced ICT (like computers and semi-conductors) were very important in driving productivity growth in the late 1990s, they are a relatively small part of the economy and the sectors that use ICT intensively have been much more important in driving productivity post 2000. These sectors are primarily service sectors (e.g. wholesale and retail trade).

There has been much less systematic investigation of the internationalisation of this sector, despite the clear importance of global services (e.g. Wal-Mart entry to the UK in the form of the takeover of Asda, global consultancy and financial service firms, and the offshoring of call centres and software design to India). One exception (discussed in detail in the First Interim Report) is Van Ark and Piatkowski (2004). They document the strong productivity growth rates of the ICT-producing industries in Central and Eastern Europe (CEE). In turn, they highlight that the relatively strong performance of the ICT-intensive sector in the CEE region was a function of internationalisation, that is, an influx of specialised, high-tech FDI.

The two questions for econometric modeling are then (i) whether the MNE productivity premium is larger for firms in the ICT-intensive sector and (ii) whether there are significant differences in productivity across ICT-intensive MNEs of different nationalities (for example, US versus European MNEs). These questions can be considered using simple extensions of the framework covered in Section III.B. For the first question we can define a production function as follows:

$$y_{ijkt} = \beta^{c} c_{ijkt} + \beta^{k} k_{ijkt} + \beta^{l} l_{ijkt} + \alpha' x_{ijkt} + \beta^{mne} MNE_{ijkt} + \beta^{cc} CC_{ijkt} + \beta^{mnecc} (MNE * CC)_{ijkt} + u_{ijkt} \qquad (35)$$

Where CC_{ijkt} is a dummy for firms in the ICT-intensive sectors (where this can be further divided into a using and producing sector and into services vs. manufacturing) and *MNE*CC* is an interaction measuring whether ICT-intensive MNEs are productive than other firms. From previous research it is well-known that $\beta^{MNE} > 0$ and $\beta^{CC} > 0$ but evidence on the interaction terms β^{MNECC} is much less common.

In answering the second question above (regarding differences on the basis of nationality) it is simpler to restrict the sample of MNE firms to those in the ICT-intensive sector only. We can then specify the following equation:

$$y_{ijkt} = \beta^c c_{ijkt} + \beta^k k_{ijkt} + \beta^l l_{ijkt} + \alpha' x_{ijkt} + \beta^{NAT} NAT_{ijkt} + u_{ijkt} \qquad (36)$$

where NAT_{ijkt} is a simple dummy for the nationality or home country of the ICT-intensive MNE (for example, a dummy for whether the home country is the US, the UK, France etc). Note that by restricting the sample to MNE and ICT-intensive firms we are able to drop the variables that measure those characteristics and focus solely on differences according to nationality. While we can expect that there will be differences between firms of different nationalities it is possible that these differences can be easily explained by observable firm characteristics (e.g. global size, the profile of 4-digit industries or simple input characteristics).

We can answer these questions by looking in more detail at the results for the UK establishment panel discussed in the previous section. Table III.7 isolates some of the relevant results. In this table we directly contrast results for the ICT-using sub-sample against all remaining establishments. Columns(1) and (2) present OLS results with controlling for firm fixed effects. This shows that there is a bigger productivity advantage for MNEs in the ICT-using sector but very importantly it is an advantage that is heavily concentrated among US-owned MNEs. The coefficient on the interaction between ownership staus and ICT capital is 0.038 (0.013) for US multinationals and 0.020 (0.007) for other types of MNE. This result is reinforced after controlling for firm fixed effects. The results (shown in columns (3) and (4)) indicate that the US-related effect persists here even while it disappears for other MNEs. This confirms both of the conjectures above, namely that a bigger productivity advantage exists MNEs active in the ICT-intensive sector and that this advantage is concentrated by nationality of ownership.

C COMPETITIVENESS, TECHNOLOGY ADOPTION AND ICT

In this final Section, we consider the impact that globalisation (and in particular, trade competition) has on technology adoption and competitiveness in the North. For policy-makers the importance of this issue can be seen in ongoing calls for Northern countries to move up the technology or quality ladder in response to the rise of import competition from the South. A number of theoretical models have considered this issue of induced innovation or technology adoption. The contribution of Thoenig and Verdier (2003) outlines a model of “defensive innovation” where competition from low-wage countries leads Northern firms to innovate in response. Another strand of the literature (Bernard, Jensen Redding and Schott (2007, 2009) looks at how compositional change can act as a mechanism for technological upgrading in the economy. The intuition of this follows that of the literature on reallocation discussed in Section I. Increased import competition will contribute towards a selection effect whereby low-tech firms reduce their employment and exit the market. In particular, the recent trade literature has discussed how this process works with respect to “multi-product firms” which can add and delete particular product lines in response to import competition or indeed, new export opportunities.

We analyse this issue for studying the effect of a recent rise in low-wage import competition from China on ICT adoption among European establishments. The rise in import competition from China since the late 1990s has been considerable, with the total share of Chinese imports in world imports rising from approximately 4% in 1999 to over 10% by 2007. As such, this rapid change in import competition provides a good opportunity to examine some hypotheses regarding trade-induced technical adoption. The two main approaches for this analysis include the specification of a technology adoption equation (as a test for "within-firm" upgrading) as well as employment and exit selection equations. The technology adoption equation can be specified as follows:

$$\ln(ICT/N)_{ijkt} = \alpha IMP_{jkt}^{CH} + \beta x_{ijkt} + u_{ijkt} \tag{37}$$

Where (*ICT/N*) is a measure of information technology in establishment *i* in four digit industry *j* in country *k* at time *t*. We will begin below with the number of personal computers (PCs), but will later study other hardware and software-based measures of ICT. IMP_{jkt}^{CH} is our measure of exposure to competition to China, *N* is the number of workers, x_{ijkt} is a vector of controls and u_{ijkt} is an error term whose properties we discuss below. We measure IMP_{jkt}^{CH} mainly as the proportion of imports in industry *j* and country *k* that are from China, where we normalise M^{China} by total imports from anywhere in the world, M^{World}. Rapid growth in Chinese import share is therefore used as a proxy for a rapid increase in trade competition from low wage countries in the industry. The vector x_{ijkt} includes controls for many other factors such as the type of establishment (e.g. single site or multi-plant), overall import intensity, skills, etc. We model the error term, u_{ijkt} as consisting of a fixed effect, a time effect and a random component, and estimate equation (37) as:

$$\Delta\ln(ICT/N)_{ijkt} = \alpha\Delta IMPS_{jkt} + \beta\Delta x_{ijkt} + v_{ijkt} \tag{38}$$

Where Δ denotes the long (five-year) difference operator[73]. Our interpretation of the trade-induced technical change hypothesis is essentially that $\alpha > 0$.

Equation (38) examines whether Chinese import competition is associated with technological upgrading on the intensive margin – i.e. within surviving plants. We also examine whether trade affects the *extensive* margin by examining employment equations and survival equations. As discussed in the previous Section, conventional models would predict that China would cause low-tech plants to shrink and die, as these are the firms competing most closely with Chinese imports.

We can estimate employment growth equations of the form:

$$\Delta\ln(N)_{ijkt} = \alpha^n \Delta IMP_{jkt}^{CH} + \beta^n \Delta x_{ijkt}^n + v_{ijkt}^n \tag{39}$$

Where the coefficient α^n reflects the association of jobs growth with the change in Chinese trade, which we would expect to be negative (i.e. $\alpha^n < 0$). We are particularly interested in whether trade has a larger effect on lower tech firms, so to capture this we include the interaction of *IMPS* with the (lagged) technology variables and estimate specifications of the form:

$$\Delta\ln(N)_{ijkt} = \alpha^n \Delta IMP_{jkt}^{CH} + \beta^n \Delta x_{ijkt}^n + \gamma^n [TECH_{ijkt-5} * \Delta IMP_{jkt}^{CH}] + \delta^n (TECH)_{ijkt-5} + v_{ijkt}^n \tag{40}$$

where TECH is a measure of the initial or baseline level of technology at the establishment-level. If Chinese trade has a disproportionately negative effect on low-tech firms we would expect $\gamma^n > 0$.

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[73] As discussed in section I we can use long-differences to mitigate the problem of attenuation bias when using first differences.

Equations (38), (39) and (40) are estimated on surviving firms. However, one of the effects of Chinese trade may be to increase the probability of plant exit. Consequently, we also estimate a fourth equation:

$$Exit_{ijk} = \alpha^{s} \Delta IMP_{jkt}^{CH} + \beta^{s} \Delta x_{ijkt}^{s} + \gamma^{s} [TECH_{ijkt-5} * \Delta IMP_{jkt}^{CH}] + \delta^{s} TECH_{ijkt-5} + v_{ijkt}^{s} \qquad (41)$$

which is defined on a cohort of establishments (or firms) who were alive in a base period and followed over the next five years. If these establishments (or firms) exited over the subsequent five years we define $Exit_{ijk}$ = 1 and zero otherwise. If Chinese imports do reduce survival probabilities, we expect $\alpha^{s} < 0$ and if high tech plants are somewhat more protected from this effect we expect $\gamma^{s} > 0$.

These models have been estimated using data for 12 European countries in AMATECH, with a large number of results reported in Tables III.8-III.10. Table III.8 presents the results for the information technology equations. Column (1) has no controls and simply shows that there is a strong and positive association in the data. This confirms the significance of the relationship illustrated in Figure 4: establishments that faced increased exposure to Chinese imports have had a significant increase in technological intensity. A ten-percentage point increase in trade with China is associated with a 4% increase in PC intensity. Column (2) includes a full set of country by year interactions and column (3) includes some establishment type controls, such as whether the establishment is part of a multi-plant firm. These experiments reduce the coefficient on Chinese imports only slightly. The dependent variable normalises PCs by the number of workers so a concern may be that the result is driven by the effect of Chinese imports on reducing jobs, rather than by increasing ICT spending. Consequently, column (4) simply includes the growth of employment as an additional control. This enters negatively suggesting that the elasticity of PCs with respect to employment is less than unity. Nevertheless, there remains a significant and positive association of ICT intensity with Chinese imports suggesting that the Chinese import coefficient does not simply reflect employment falls.

Table III.9 starts to examine the extensive margin by examining employment growth (still of survivors). In Figure 5 we illustrate the differential employment growth by exposure to “high” and “low” Chinese import competition. The econometric specifications follow those in Table III.8. First we examine the raw correlations in column (1) suggesting a strong negative association between job growth and exposure to Chinese imports. This suggests a ten-percentage point increase in Chinese imports is associated with a 2.8% fall in employment. Lagged ICT intensity enters with a positive and significant coefficient in column (2) suggesting that the more technologically advanced firms in were more likely to grow over the next five years. This reduces the magnitude of the trade effect to 0.203. Column (3) includes the interaction of Chinese trade and lagged ICT intensity that enters with a positive and significant coefficient. This suggests that firms that are ICT intensive are somewhat “shielded” from the effects of Chinese imports.

This is made even clearer in the next column when we divide our firms into five quintiles groups based on their lagged ICT intensity and we interact these with Chinese import growth. A clear pattern emerges whereby the imports effect is much weaker for the more ICT intensive firms. In fact, for establishments in the top quintile there is no association of Chinese imports with job losses. By contrast, for those who were in the bottom quintile of the ICT distribution a ten percentage point increase in Chinese imports is predicted to reduce employment by 4%. The final column shows similar results using patents as an alternative measure of technology.

The direct effect of Chinese competition on employment can also be summarized following the results in column 93). Given a 5-year increase in Chinese competition of 0.025 and a coefficient of 0.4 this indicates that the China effect reduced employment by 1% over 5-years. This compares to an overall 5.8% fall in employment across our sample. Therefore, these figures suggest that the China effect is responsible for approximately one-sixth of the total fall in manufacturing employment that we observe here.

Table III.10 examines models of survival where we consider a cohort of firms alive in 2000 and model the subsequent probability that they survived until 2005 as a function of the growth of industry-wide Chinese imports and their initial characteristics. Column (1) shows that even after conditioning on (lagged) establishment size and PC intensity, establishments more exposed to Chinese imports are significantly less likely to survive (i.e. more likely to exit) than those less exposed. A ten percentage point increase in Chinese imports increases the exit probability by 1.2 percentage points. Since the average survival rate in our sample period is 88.6%, this represents about a 1.4% decrease in survival rates (equivalent to an 11.4% increase in exit rates), which is a non-trivial effect. Larger establishments are more likely to survive as we would expect.

Column (2) includes an interaction of lagged ICT intensity with Chinese imports. As with the employment equations, the low-tech firms appear most “at risk” from Chinese import competition, as the coefficient on the interaction between Chinese imports and ICT intensity is positive (although it is not significant). Column (3) reports the specification where we use the quintiles of the ICT intensity instead of the linear ICT intensity. This indicates that the least technologically intensive establishments in the bottom quintile (the omitted base) are significantly *less* likely to survive when Chinese imports grow than the other groups, as the coefficients on all other interactions with the higher quintiles are PC intensity are positive. We show this most clearly in the final column where we include only the bottom quintile interaction with Chinese imports. This takes a negative and significant coefficient indicating that the effect of Chinese imports on establishment survival is confined to these low-tech firms (outside the bottom quintile of the ICT intensity distribution the effect on survival is still negative, but it is small and insignificantly different from zero). The final column shows a similar result for patents – firms with a higher patent stock are significantly more likely to survive when faced by a Chinese import shock.

SUMMARY OF SECTION III

- We find clear empirical evidence that MNEs locate their low-tech tasks in low-wage countries (in our example, China) and retain their more complex tasks for home country production. This evidence is based on a sample of the Top 100 multinationals from the US, Japan and Europe and covers all manufacturing industries.

- Specifically, we find that a multinational subsidiary located in China (the major global site for low wage production) is 11% more likely to be classified as “low-tech” according to our technology ladder indicator. This effect is evident even when control for the global ultimate owner meaning that this is strong “within-firm” phenomenon. There is also evidence that the major multinationals are 6% more likely to keep high-tech activities in their home country. However, this finding is not as strong in terms of within-firm effects.

- Multinational firms are more ICT-intensive than domestic firms and have a productivity advantage that is systematically related to this ICT usage. Furthermore, US multinationals have a further productivity edge in the usage of ICT at the firm-level. The US advantage in ICT-usage is related to “people management” practices in terms of promotion, pay and personnel decisions, and incentives.

- The example of US MNE firms operating in Europe also provides a good capsule for calibrating overall US-EU productivity differences. Firstly, production function results for the UK sample indicate that US firms experienced 0.8% per year faster labour productivity growth in the 1995-2004. When weighted by the proportion of ICT using firms this then accounts for half of the US-EU labour productivity growth differential. This part of the gap represents the US-specific advantage in using a given level of ICT capital. The remaining half of the gap can be attributed firstly to the advantage that US firms gain from possessing higher levels of ICT (this accounts for approximately 25% of the gap) and secondly to other firm characteristics such as skills.

- There are close links between this finding regarding the organisational capital of firms and Section I's earlier findings on the general effect of labour and product market regulation on productivity. In particular, it could be argued that the finding on US multinationals in Europe suggests that LMR and PMR may be less important since US firms still perform well in a more regulated environment. However, this can be qualified in two ways. Firstly, lower levels of LMR and PMR in the US have lowered the costs of developing organisational capital. Hence, the regime of LMR and PMR in the US has contributed to the development of efficient management practices which are then exported to overseas subsidiaries. Secondly, our analysis is silent on the *relative* performance of US multinationals in their home country compared to overseas locations. The presence of higher adjustment costs in locations such as Europe could create a gap between the performance of US firms at home and overseas. That is, while US firms are able to perform better due to their higher endowments of organisational capital they are not able to fully exploit these assets due to the adjustment costs imposed by higher levels of LMR and PMR.

- We find that trade is an important driver of ICT adoption. Specifically, we find that recent low-wage competition from China has played a leading role in trade-induced innovation. This effect occurs through two mechanisms. Firstly, a "within-firm" effect occurs where firms industries heavily exposed to Chinese competition upgrade their ICT. Secondly, there are selection effects whereby high-tech firms are more likely to survive given levels of trade-based competition. This selection effect occurs as an extra dimension to the reallocation effect we first identified in Section I of the report.

- In total, the low-wage competition effect can account for 15% of the total increase in PC intensity in manufacturing between 2000-2007 in Europe. The "within-firm" effect accounts for approximately 11% of this total with the "between firm" selection effect making up the remaining 4%.

CONCLUSIONS

A OVERALL CONCLUSIONS

There are a large number of complex issues to consider in tackling the economic impact of ICT. Our belief is that the best approach is a methodology grounded in a firm level micro approach that is then aggregated to assess the macro impact (“micro to macro”). We have shown how a workable methodological framework is possible based around a system of three key equations (productivity, ICT adoption and innovation). These can be expanded to deal with many of the most subtle issues to be investigated. We described the type of data necessary – firm level longitudinal data covering many industries in many European countries. We have illustrated the approach with some detailed and extensive results from these international micro-panel databases. In this conclusion we discuss some future scenarios and projections for the ongoing economic impact of ICT and summarise our key findings. Note that we do not summarise every finding here (see the Executive Summary for this), but mention what we think are the most policy-relevant findings.

Our work has uncovered an important average effect of ICT on firm (and therefore macro) productivity in Europe. There is not a single effect, however, but rather a heterogeneous impact of ICT which depend on other firm-level factors. We have stressed that management practices (in particular over human resources – promotion, pay, hiring and firing) and organisational structures (in particular, the degree of decentralisation) can substantially increase the positive effect of ICT on firm performance. Policies which foster these complementary inputs will raise the return to ICT investments and therefore encourage their faster diffusion. Increasing competition, raising human capital, lowering barriers to trade and foreign investment, removing distortions to the tax system that favour family firms and increasing labour market flexibility should all encourage the types of organisational capital that help increase Europe’s ICT and resume the catching up process with the US.

We found little evidence for the kind of large and pervasive positive ICT spillovers that are needed to justify widespread subsidies for ICT. Apparent spillovers in terms of productivity are not robust to controlling for industry and regional effect or other basic statistical checks. However, spillovers are evident for the adoption of particular technologies but this effect may occur through channels such as learning or network effects that do not have an ultimate productivity effect. Furthermore, there are certainly knowledge spillovers from research as the work on university patents illustrates but these are weaker for ICT-related inventions. The first production of an ICT innovation like the Internet or ERP certainly has spillovers, but the use of existing ICT (i.e. diffusion) does not. Thus although research into R&D in ICT has a strong policy justification, generalised subsidies for using ICT do not. Furthermore, we did not find evidence that ICT has a strong effect in increasing innovation as measured by patents, which would be an alternative justification for subsidies. What we do see though is a potential role for ICT as a vehicle for product and process innovation. The success of these types of innovations at the firm-level hinges on the managerial and organisational inputs of firms and this is where policy effort should be concentrated.

Finally, we found that ICT had no tendency to concentrate industrial activities in services and actually tended to cause spatial dispersion in manufacturing. Since services represents a large and growing proportion of economic activity this could contribute to increased regional inequality as activity becomes more concentrated. However, the relationship between concentration and ICT was statistically weak and a major caveat needs to be applied to this conclusion.

In sum, this work has shed considerable light on analysing the economic impact of ICT. We would encourage the Commission to continue to gather high quality micro-data on ICT and productivity. Many of the reforms that the Commission has been supporting for other reasons such as widening the Internal market through the Services Directive, removing barriers to trade and investment and unnecessary labour market regulations – are found to be pro-ICT. Since improvements in ICT quality are likely to persist, the lessons from this Report will remain salient over the next decade.

B SCENARIO PLANNING

A final issue is the future development of ICT as a driver of economic growth. For a more rigorous attempt to do this in the context of ICT and productivity growth the reader is referred to the recent EU-funded work of van Ark et al (2008) and Jorgenson et al (2008) who try to do this more explicitly using EU-KLEMS data.

Nevertheless, we sketch a framework for thinking here based on two approaches. Firstly, we discuss the growth accounting projections of Jorgenson et (2008) which provide alternative scenarios for the evolution of ICT and productivity in the next 10-20 years. Secondly, we consider the implications of a qualitative scenario analysis of future technological trends. Specifically, we will put these technological trends into the context of the growth accounting to suggest a basic principle for developing robust scenarios.

(i) Growth Accounting

The growth accounting approach assumes that the fundamental reason for the US productivity acceleration post 1995 lies in the technological acceleration of production in the semi-conductor industry. This led to quality adjusted ICT prices falling from around 15% per annum to 30% per annum. In turn, this lead to both an increase in TFP growth in the ICT producing sectors and an increase in labour productivity growth in the sectors than intensively used ICT. Furthermore, countries that had an economic environment conducive to high levels of complementary factors to ICT (like the US) took advantage of this fall in ICT prices first, which is why European productivity growth did not immediately accelerate after 1995. These complementary factors include people management practices, decentralisation and human capital documented in our report. They are stimulated *inter alia* by high quality universities and flexibility in product and labour markets. Over time, these complementary factors are accumulated when ICT prices fall, so we see faster productivity growth in those sectors that were intensive in ICT usage (e.g. retail and wholesale).

In this framework a lot depends on forecasts of technological change in the ICT producing sector (e.g. semi-conductors). Following Jorgenson et al (2008) we distinguish between an "optimistic" scenario where ICT prices fall at 30% p.a. from 2010, a baseline where they continue at a "normal" pace of 15% p.a. post 2010 and a "pessimistic" scenario where they slow to falling at 5% p.a. post 2010. We are abstracting away from all other imponderables such as the deep recession and the growth of China which are difficult to factor in.

Baseline Scenario: Under this scenario the 1995-2010 period was a one-off acceleration. US labour productivity growth returns to around 2.4% p.a. after 2010. The EU lags behind the US because of slower organisational change and as a result post 2005 productivity growth is relatively good as it catches up to US levels in 2020. Consequently productivity growth in the EU outstrips that of the US between 2010-2020 and perhaps prior to this (if there is a 10 year lag, the takeoff in EU productivity growth took was around 2005/6 and has been disguised by changes in labour quality and the recessionary turmoil). After 2020 EU productivity growth is the same as the US as things return to normal.

Optimistic Scenario: Under this scenario, ICT prices return to falling at 30% pa post 2010. The US experiences a continuation of the productivity boom. The EU also shares in this benefit but again with a lag. If we assume this is 10 year, EU productivity growth matches the US around 2005 and continues to grow at about the same rate. However, because of lower organisational capital there is a permanent productivity gap between the EU and the US. Note that this is optimistic because EU (and US) consumers are better off, even though policy-makers may not like the continuing EU-US gap in productivity levels.

Pessimistic Scenario: Here, ICT prices fall much less than historical experience post 2010. US Productivity growth will fall (perhaps below the 1973-1995 level). EU productivity growth will be faster than the historical average 2005-2020 and faster than the US 2010-2020 as it enjoys the lagged blast of the ICT price fall. However, post 2020 both US and EU will grow at a historically low rates (say c. 1.4% p.a.).

It is impossible to know the future evolution of ICT prices and very limited amounts that policy-makers can do to affect these (except maybe reducing trade barriers with the producers of such goods - increasingly China - and supporting basic research in the ICT field). The two fundamental factors that will influence which scenario eventuates lie firstly in producer prices for ICT goods and secondly in the evolution of the intensive ICT using sectors. This latter point has a particular role in understanding the implications of the technological trends that we now consider.

(ii) Technological Trends

The recent RAND Europe report on “Trend in Connectivity Technologies and their Socio-Economic Impacts” identifies four major trends in the development of ICT. We summarise each one in turn and then put them into the context of our economic analysis.

Infrastructure Convergence: This technological trend primarily relates to the development of more integrated platforms of ICT usage and delivery. The most topical current examples are the convergence of the internet with television viewing and the emergence of mobile computing through the rise of “smart phones”. Another feature of this trend is the perceived “flatness” of technology whereby differences in platforms become less noticeable. Again, the best current example is the trend towards internet browsing on smart phones which breaks down the distinction between desktop computing and mobile communications. The drivers of this trend are improvements raw processing power and broadband infrastructure – without these ingredients the infrastructure convergence trend could stall.

Human-Computer Convergence: Technically, this trend encompasses the integration of human cognition with computing up to the limit of “cybernetic organisms”. It also includes the rise of “artificial life” environments as well as older cyberpunk fads such as virtual reality and artificial intelligence. More practically, this trend is best interpreted as the ongoing diffusion of computing into contexts outside of the desktop or office environment. The classic current examples are the increasing use of embedded sensors and the rise of RFID tagging technology in logistics. A further emerging development relates to improvements in the technology of identification. These technologies will facilitate more secure online interactions, particularly with respect to service delivery.

Utility Computing: The utility computing trend is a counterpart to infrastructure convergence. Specifically, utility computing is based around the enhanced availability of computer power and storage. The current high concept in this field is “cloud computing” where programmes and information storage are conducted through the web rather than via installation to desktop workstations. Like infrastructure convergence this trend relies heavily on increases in processing power and external internet infrastructure.

The Intelligent Web: This trend could be described as a type of “Web 3.0” and seems to be based on much more intensive interactive applications. The examples given include *World of*

Warcraft and *SecondLife*. It is anticipated that such applications could be useful as formal economic tools as well as entertainment.

Providing an economic interpretation of the above trends is in some ways straightforward. The fundamental impact of these trends can be understood in terms of the intensive and extensive margins of ICT usage in the economy. On the intensive margin developments such as “cloud computing” should lower the cost of ICT giving smaller enterprises access to more powerful computing resources. On the extensive margin infrastructure and human-computer convergence is set to increase the economic possibilities for ICT-usage. That is, as computing moves outside of the standard desktop environment it could become integrated with new economic applications. The diffusion of RFID sensors is probably the best current example.

In practice, these trends bear on the likelihood of the second, optimistic growth accounting scenario unfolding. In particular, these trends could operate as new drivers of technological acceleration. That is, while falling semi-conducter prices drove the technological acceleration experienced post-1995 these new trends could induce similar price falls or increases in the quality of ICT over the next 10-15 years. The caveat of course is the evolution of these trends is highly uncertain. The main conculsion here is that the technological trends should be evaluated in terms of how they affect the intensive and extensive margins of ICT usage in the economy.

C FUTURE RESEARCH

Although tremendous progress has been made in examining the impact of ICT on productivity in the last decade there remain several areas where research is needed. Based on the findings of the report we have identified a number of areas firstly related to important research topics raised by the analysis and then to specific data issues.

(i) Research Topics and Questions

Policy Levers and ICT: We have speculated on the type of policies that would be beneficial to ICT diffusion, namely those policies that would assist the accumulation of complementary human and intangible capital. But formal evaluation of policy experiments that could affect ICT are still rare and would be beneficial for future policy design.

Two types of research would be valuable here. Firstly, there is a need for the ex post evaluation of ICT-related tax and subsidy policies that have already been implemented by governments. For example, working with governments who have introduced explicit incentives for ICT, such as tax incentives, researchers could work out the effects of the policy using different techniques from the “treatment effects” literature. This is hard to do without administrative data on government programmes and interventions. Ideally Governments could even be encouraged to include some kind of evaluation process in the policy. For example, rolling out ICT tax credits to a trial areas initially and then all areas a year or so later to evaluate the impact. See Criscuolo et al (2009) for an example of a quasi-experimental evaluation of a government business intervention programme.

Second, a more macro approach would analyze large-scale policy changes in many areas (e.g. labour market liberalisation, increases in local education) and examine the impact of this on ICT takeup. In this report we examined an example of this type of research design in our study of the French automobile market. As we discuss in regard to data issues below this approach could be “scaled up” across different types of policy reforms using some emerging datasets on labour and product market reforms.

Causal Impact of ICT on Firm Performance: We have reported much evidence suggesting that ICT improves productivity using simple methods and state of the art econometric techniques. Our two main strategies for dealing with endogeniety concerns were, firstly, to directly measure unobserved heterogeneity at the firm-level, and, secondly use dynamic panel data methods to account for the endogeniety of firm input choices.

However, there is still a need to consider ICT adoption and productivity parameters (ie: elasticities) in the framework of causal identification. There are few examples in the literature of quasi-experiments (such as changes in policies), randomized control trials or regression discontinuity designs. Without such credible "instruments" there are still concerns over identification and whether we really have found a causal impact. Probably the best examples come from the economics of education looking at the impact of computers in schools (Angrist and Lavy, 2002; Machin et al 2007).

Future research needs to focus on this area both using existing evidence, such as policy changes. As noted above if some policies do have an effect on ICT, these can be used to identify the causal impact of ICT on productivity and other factors. Another method would be promoting the use of randomized control trials of the introduction of different types of ICT. We have been involved recently in randomized experiments on firms in India changing management practices (Bloom et al. 2009), and found large causal effects on firm performance. Ideally a budget could be provided to, for example, fund ICT investments in a randomly selected set of treatment firms (say 250) and compare these to a set of control firms where little/no ICT subsidies have been given (say another 250 firms). Collecting data before and after the intervention on both sets of firms would enable a direct evaluation of the impact of ICT on firm performance.

Disaggregating the types of ICT: Too many studies still treat ICT as a homogenous factor, whereas we have shown that disaggregating ICT is important. For example, our work on organisational decentralization (and therefore on inequality and performance) suggested that falls in the cost of ICT have the opposite effects (reducing centralization and inequality) to falls in the cost of communication (increasing centralization and inequality). Thus looking more carefully at the component parts of ICT – hardware, software and communication at least – but also within these categories, is important. This report has taken a major first step in constructing measures of tangible and intangible ICT capital at the firm-level (section II.B) but there is still scope to extend this work. For example, (i) the current measures of firm-level intangible could be improved using measures of prices for particular types of hardware and software; and (ii) information on intangible capital could be collected as part of firm-level surveys by statistical offices.

Complementarities with ICT: We have emphasised the importance of organisational complementarities with ICT, but the existing datasets on organisation and management are extremely sparse, generally being one off surveys by researchers. Moreover, the management and organisational data is typically collected as a particular point in time so the identification can only come from changes in the ICT inputs rather than management inputs. Some of the key questions on management practices need to be part of the standard way that data is collected by national agencies. The combination of such data with information on ICT, skills and productivity is a major task ahead. We are currently working with the US Census Bureau to add a supplement with questions on management practices to their mandatory Annual Survey of Manufacturing, to provide a panel on organisational, management and ICT data for around 40,000 US establishments. Having European Census agencies run similar surveys would be extremely helpful for informed European policy making.

What is special about ICT?: One more theoretical line of research is what is "special" about ICT. The general purpose nature of ICT is one aspect which makes ICT special, but in many respects it is simply the latest wave of new technologies that have been sweeping the world for centuries.

Thus, a question is whether the lessons from ICT can be applied to future types of technical change. Seen from another perspective, what lessons from past waves of technical change can be applied to ICT. Existing comparisons of the development of electricity and the development of computers would be an example of the historical approach. This is important for policy-making since our results in section I and III suggest that Europe did not enjoy the same productivity miracle as the US because it's people management practices meant European firms were inflexible. Their inability to aggressively hire, fire, pay and promote employees left them inflexible and unable to rapidly exploit new ICT technologies. But this implies that when the next wave of technology occurs that European productivity will once again drop behind the US unless her people management practices are changed.

ICT and Prices: The report uncovered an important link between ICT and falls in producer prices in the US and Europe. Future research in this area needs to consider two issues: firstly, research is needed to explore whether productivity growth is the main mechanism driving the link between ICT and producer prices and secondly, research is needed to map producer prices to specific retail price categories. The second issue is important for both understanding the welfare impacts of ICT on consumers and measuring the effect of ICT as a potential determinant of inflation.

ICT in the Public Sector: The majority of the research on the impact of ICT has occurred in manufacturing because the availability of both ICT input and production output data in this sector. Some researchers have also looked at service sectors, but this is generally the exception rather than the rule. However, very little work has been undertaken on ICT and productivity in the public sector beyond isolated studies, such as Heaton and Garicano (2009) work on police productivity and ICT. But ICT has the potential to generate large productivity improvements in the public sectors, for example as the high-level push for computerization of patient records in both the US and Europe testifies. The potential productivity impact for ICT is probably much greater in the public sector – for example hospitals, schools, prisons and the police – than in the private sector, because the public sector has so far been extremely slow to adopt ICT. Thus, more data collection and analysis on ICT and productivity in the public sectors would be extremely valuable for policymakers, particularly as they have a greater ability to act on any findings for more effective use of ICT in the public sector.

Universities and Knowledge Producing Industries: Our study in section I indicated that universities may have a role as policy levers for the development of localized knowledge spillovers. In turn, these knowledge spillovers are the seed of high-tech, knowledge production clusters of firms. No comprehensive dataset on European university inventions and institutional structures currently exists and it would be productive to construct one from EPO and other complementary data. It must be noted however that this type of study would inform knowledge economy generally rather than ICT policy specifically.

(ii) Data Issues

In terms of data, much has been achieved at the industry level through the EU-KLEMS project and ongoing efforts at Eurostat. There have also been major co-ordinated efforts aimed at building internationally comparable firm-level data (for example, by the OECD, various statistical institutes, and the authors of this report). These efforts need to continue since as this report has shown many new insights can be gained from micro-level analyses.

In practice, one of the main problems with research in this area actually lies in complementary industry, regional and skills data. It is still the case that much more complete and detailed complementary data is available for the US as compared to Europe. As such, we flag the following gaps in complementary data which impede research at the industry and firm-level.

Industry-level Databases : A major gap still exists in Europe with respect to a comprehensive 4-digit industry database on inputs and outputs. The "raw materials" of a detailed database exist in some Eurostat databases but this needs to be consolidated in a specialized project, probably as part of EU-KLEMS. A good model for this type of database is the recently updated

Bartelsman, Becker and Gray (2000) NBER project which provided long run data on US 4-digit industries. This type of data would be useful even if it was available for a subset of the larger countries in the EU.

Education and Skills: It is still very difficult to construct detailed, region-specific skills data for Europe. In the US this is typically achieved by directly manipulating labour force surveys such as the Current Population Survey (CPS). Currently the European Labour Force Survey (ELFS) does not have sufficient detail, availability and coverage to support the type of analysis that is conducted on the CPS.

Labour and Product Market Regulation: A major theme of the report has been the impact of labour and product market regulation on productivity outcomes. The research in this area has mainly been conducted using highly aggregated country-level indexes of regulation. Sharper research designs are needed that exploit country, time and industry changes in regulation. An untapped resource on this topic is the EU Commission's LABREF and MICREF on labour market and microeconomic reforms respectively. One useful project here would be to map specific, major reforms to particular industries, regions or countries. The analysis of regulation changes in the French automobile market (in section II.B) is an example of the type of study that can be rolled out to other cases.

Combining Databases: In this report we have focused on private sector databases that have generally not been used by researchers such as the Harte-Hanks (HH) data. These can, in principle, be combined with existing National Statistics databases that have been used in various ways by other researchers either at the micro-level (the ONS initiative) or the industry level (KLEMS). For example, the HH data could be brought into the National Statistical agencies and compared with existing firm and establishment level surveys. Many of the items are complementary as HH contains the exact piece of equipment in place in a site whereas the Statistical Agency surveys are often expenditure on hardware or software as a whole. In other cases it might be that the agencies are duplicating work that is already done in the private sectors. There would also be tremendous value from combining datasets across countries, so that for example researchers can jointly examine Census data from the UK, France and Germany at the same time. This is important when policies vary by country, so that careful examination of the impact of policies requires cross-country micro data. At present analysis has to be run on a country by country basis with Census data and then compared, but this is difficult not least because harmonizing the cleaning and treatment of the data is difficult at distance.

TABLE I.1: DESCRIPTIVE STATISTICS FOR EUROPEAN PRODUCTION - FUNCTION SAMPLE

Variable	Mean	Std Dev
Employees	398.2	4731.5
Employees (median)	140	
Sales (1,000,000s $USD)	140	200
PCs per person	0.501	0.368
Capital per employees (1000s $USD)	42.5	58.9
HQ-site	0.111	-
Branch-site	0.151	-
Coverage ratio	0.92	0.322
Publicly Listed	0.018	-
Multinational (All types)	0.19	
US Multinational	0.063	
Patent Stock	0.191	2.6
Cite-weighted Patent Stock	0.1	2.1
Number of Firms	19,142	
Number of Observations	87,953	

Notes: Main AMTECH sample of Harte-Hanks establishment-level data matched to AMADEUS company accounts. Countries include: Austria, Switzerland, Germany, Denmark, Spain, Finland, France, Great Britain, Italy, Netherlands, Norway, Poland and Sweden. Branch-site and HQ-site represent the proportion of production and HQ type establishments per company (where establishments are weighted by employment).

TABLE I.2: PRODUCTION FUNCTION ESTIMATES – EUROPE and the US; 1996-2008.

(a) European Sample Only

	(1)	(2)	(3)	(4)
Dependent Variable	ln(Y)	ln(Y)	ln(Y)	ln(Y)
	OLS Levels	Within Groups	Olley-Pakes	GMM-SYS
ln(ICT/L)	0.091***	0.023***	0.060**	0.089***
log(ICT/Employment)	(0.005)	(0.003)	(0.028)	(0.036)
ln(K)	0.143***	0.083***	0.220***	0.119***
log Capital	(0.005)	(0.006)	(0.009)	(0.056)
ln(L)	0.762***	0.710***	0.648***	0.812***
log Employment	(0.010)	(0.019)	(0.011)	(0.078)
AB Test – AR(1)				-16.73
				(0.000)
AB Test – AR(2)				1.31
				(0.190)
				248.58
Sargan Test				(0.000)
Number of Firms	19,142	19,142	6,139	6,139
Number of Observations	80,223	80,223	32,257	32,257

Notes: * significant at 10%; ** significant at 5%; *** significant at 1%. Standard errors clustered by firm in parentheses below coefficients. Variables normalised by sic2-country-year means. Standard controls include country-year effects, site-type dummies, coverage polynomials, number of establishments in company group. Olley-Pakes uses a second order polynomial in the control function (selection correction included). Countries include: Austria, Switzerland, Germany, Denmark, Spain, Finland, France, Great Britain, Italy, Netherlands, Norway, Poland, and Sweden.

(b) Europe and US Comparisons

	(A)		(B)	
	OLS with SIC4 Effects		Within Groups	
	(1)	(2)	(3)	(4)
Dependent Variable	ln(Y)	ln(Y)	ln(Y)	ln(Y)
	US	Europe	US	Europe
ln(ICT/L)	0.035*	0.091***	0.020*	0.023***
log(ICT/Employment)	(0.019)	(0.005)	(0.011)	(0.003)
ln(K)	0.316***	0.143***	0.301***	0.083***
log Capital	(0.009)	(0.005)	(0.022)	(0.006)
ln(L)	0.685***	0.762***	0.685***	0.710***
log Employment	(0.016)	(0.010)	(0.016)	(0.019)
SIC4 Effects	Yes	n/a	Yes	n/a
Number of Firms	555	19,142	555	19,142
Number of Observations	3,946	80,223	3,946	80,223

Notes: * significant at 10%; ** significant at 5%; *** significant at 1%. Standard errors clustered by firm in parentheses below coefficients. European samples details as above. US sample based on matched Harte-Hanks COMPUSTAT data and includes the years 1996-2008.

TABLE I.3: HETEROGENEITY IN THE IMPACT OF ICT, EUROPEAN FIRMS 1999-2008.

	(1)	(2)	(3)	(5)	(4)
Dependent Variable	ln(Y/L)	ln(Y/L)	ln(Y/L)	ln(Y/L)	ln(Y/L)
	Baseline	Firm Size	Firm Age	High-tech region	ICT using
ln(ICT/L)	0.023***	0.024***	0.023***	0.023***	0.017***
log(ICT/Employment)	(0.003)	(0.006)	(0.004)	(0.003)	(0.005)
ln(ICT/L)*Smaller Firms		-0.001			
		(0.006)			
ln(ICT/L)*Young Firms			0.001		
			(0.006)		
ln(ICT/L)*High Tech Region				-0.003	
				(0.016)	
ln(ICT/L)*ICT-Using					0.015***
					(0.006)
Firm fixed effects	Yes	Yes	Yes	Yes	Yes
Number of Observations	80,223	80,223	80,223	80,223	80,223

Notes: * significant at 10%; ** significant at 5%; *** significant at 1%. Standard errors clustered by firm in parentheses below coefficients. Capital and labour terms suppressed. Sales and capital normalised by employment. “Young firms” defined as those with less than 25 years since incorporation date. “Smaller firms” defined as those with under 250 employees. “High-Tech Region” defined as the regions in the upper quintile of the distribution of PCs per person (pooled across all European observations). Standard controls include country-year effects, site-type dummies, coverage polynomials, number of establishments in company group. Olley-Pakes uses a second order polynomial in the control function (selection correction included). Countries include: Austria, Switzerland, Germany, Denmark, Spain, Finland, France, Great Britain, Italy, Netherlands, Norway, Poland, and Sweden.

TABLE I.4: REGIONAL AND INDUSTRY SPILLOVERS – EUROPE 1999-2008

(a) Region-Level Only Spillovers (NUTS1 level)

Dependent Variable	(1) ln(Y/L) Baseline	(2) ln(Y/L) Fixed Effects	(3) ln(Y/L) Within Groups	(4) ln(Y/L) Weight by Cell
ln(REGSPILL)	0.225***	-0.005	-0.004	0.001
	(0.007)	(0.003)	(0.025)	(0.003)
Type of Fixed Effects	SIC4	SIC4*NUTS1	Firm	Firm
Type of Weighting	HH Coverage	HH Coverage	HH Coverage	HH Coverage*Cell
Observations	80,210	80,210	80,210	80,210

(b) Region-Industry Spillovers (NUTS1 – SIC2 level)

Dependent Variable	(1) ln(Y/L) Baseline	(2) ln(Y/L) Fixed Effects	(3) ln(Y/L) Within Groups	(4) ln(Y/L) Weight by Cell
ln(SICSPILL)	0.095***	0.034**	-0.003	-0.013
	(0.013)	(0.015)	(0.007)	(0.011)
Type of Fixed Effects	SIC4	SIC4*NUTS1	Firm	Firm
Type of Weighting	HH Coverage	HH Coverage	HH Coverage	HH Coverage*Cell
Observations	80,104	80,104	80,104	80,104

Notes: * significant at 10%; ** significant at 5%; *** significant at 1%. Standard errors clustered by firm in parentheses below coefficients. Capital and labour terms suppressed. Sales and capital normalised by employment. REGSPILL is defined as the weighted average PC intensity for all firms in a NUTS1 region cell. SICSPILL is defined as the weighted average of PC intensity in a NUTS2-SIC2 cell. All regressions include the weighted average of employment in the spillover cell as an extra control (to make sure Spillovers coefficient is not reflecting the denominator). Standard controls include country-year effects, site-type dummies, coverage polynomials, number of establishments in company group. Countries include: Austria, Switzerland, Germany, Denmark, Spain, Finland, France, Great Britain, Italy, Netherlands, Norway, Poland, and Sweden.

TABLE I.5: COUNTRY HETEROGENEITY IN THE IMPACT OF ICT ON FIRM LABOUR PRODUCTIVITY, EUROPEAN FIRMS 1999-2008.

	(1) ln(Y/L) SIC2 Effects	(2) ln(Y/L) SIC3 Effects	(3) ln(Y/L) SIC4 Effects	(4) ln(Y/L) Extra Interactions	(5) ln(Y/L) MNE Dummies	(6) ln(Y/L) Firm Fixed Effects
ln(ICT/L)	0.238***	0.225***	0.218***	0.216***	0.204***	0.014**
	(0.012)	(0.012)	(0.011)	(0.011)	(0.011)	(0.007)
ln(ICT/L)*france	-0.097***	-0.084***	-0.075***	-0.073***	-0.066***	-0.007
	(0.015)	(0.014)	(0.014)	(0.014)	(0.014)	(0.008)
ln(ICT/L)*germany	-0.152***	-0.134***	-0.127***	-0.125***	-0.119***	-0.034***
	(0.020)	(0.019)	(0.018)	(0.018)	(0.018)	(0.013)
ln(ICT/L)*italy	-0.079***	-0.072***	-0.059***	-0.062***	-0.055***	0.010
	(0.017)	(0.016)	(0.016)	(0.016)	(0.016)	(0.012)
ln(ICT/L)*spain	-0.071***	-0.063***	-0.055***	-0.051***	-0.044***	-0.017
	(0.017)	(0.016)	(0.016)	(0.016)	(0.016)	(0.011)
ln(ICT/L)*austria	-0.085**	-0.066	-0.055	-0.051	-0.049	0.074
	(0.039)	(0.041)	(0.040)	(0.040)	(0.040)	(0.069)
ln(ICT/L)*sweden	-0.105***	-0.088***	-0.082***	-0.087***	-0.078***	-0.006
	(0.022)	(0.022)	(0.021)	(0.021)	(0.021)	(0.013)
ln(ICT/L)*norway	-0.066*	-0.043	-0.043	-0.038	-0.034	-0.025
	(0.040)	(0.038)	(0.037)	(0.037)	(0.037)	(0.021)
ln(ICT/L)*finland	0.016	0.031	0.036	0.035	0.043	0.005
	(0.028)	(0.027)	(0.027)	(0.026)	(0.026)	(0.017)
ln(ICT/L)*denmark	-0.092**	-0.087**	-0.075**	-0.084**	-0.080**	-0.035*
	(0.040)	(0.040)	(0.038)	(0.038)	(0.038)	(0.020)
ln(ICT/L)*netherlands	-0.100**	-0.094**	-0.098**	-0.096**	-0.097**	-0.009
	(0.045)	(0.045)	(0.045)	(0.043)	(0.043)	(0.034)
ln(ICT/L)*swiss	0.066	0.122	0.182	0.063	0.059	0.006
	(0.161)	(0.177)	(0.161)	(0.081)	(0.082)	(0.030)
ln(ICT/L)*poland	0.213***	0.205***	0.199***	0.134***	0.138***	-0.039
	(0.047)	(0.047)	(0.046)	(0.046)	(0.047)	(0.038)
SIC2 Fixed Effects	Yes	n/a	n/a	n/a	n/a	n/a
SIC3 Fixed Effects	No	Yes	n/a	n/a	n/a	n/a
SIC4 Fixed Effects	No	No	Yes	n/a	n/a	n/a
Firm Fixed Effects	No	No	No	No	No	Yes
Number of Observations	81,188	81,188	81,188	81,188	81,188	81,188

Notes: * significant at 10%; ** significant at 5%; *** significant at 1%. Standard errors clustered by firm in parentheses below coefficients. Capital and labour terms suppressed. Sales and capital normalised by employment. Extra interactions in column(4) are country interactions for the suppressed labour and capital terms in the production function. Standard controls include country-year effects, site-type dummies, coverage polynomials, number of establishments in company group. Countries include: Austria, Switzerland, Germany, Denmark, Spain, Finland, France, Great Britain, Italy, Netherlands, Norway, Poland, and Sweden.

TABLE I.6: COUNTRY HETEROGENEITY IN PRODUCTIVITY AND ICT - LABOUR AND PRODUCT MARKET REGULATION, EUROPEAN FIRMS 1999-2008.

	(1) ln(Y/L)	(2) ln(Y/L)	(3) ln(Y/L)	(4) ln(Y/L)	(5) ln(Y/L)	(6) ln(Y/L)
ln(ICT/L)	0.223***	0.002	0.261***	0.002	0.224***	0.007
	(0.015)	(0.007)	(0.023)	(0.011)	(0.023)	(0.012)
ln(ICT/L)*Dismissal Index	-0.096***	0.003				
	(0.021)	(0.011)				
ln(ICT)*Labour Regulation			-0.149***	0.002		
			(0.034)	(0.017)		
ln(ICT)*Product Market Regulation					-0.026***	-0.001
					(0.010)	(0.005)
Dismissal Index	-1.804***	-				
	(0.535)					
Labour Regulation			18.990***	-		
			(7.267)			
Product Market Regulation					-0.308***	-
					(0.067)	
SIC4 Fixed Effects	Yes	n/a	Yes	n/a	Yes	n/a
Firm Fixed Effects	No	Yes	No	Yes	No	Yes
Number of Observations	81,188	81,188	81,188	81,188	81,188	81,188

Notes: * significant at 10%; ** significant at 5%; *** significant at 1%. Standard errors clustered by firm in parentheses below coefficients. Capital and labour terms suppressed. Sales and capital normalised by employment. Extra interactions with labour and capital terms in the production function included in all specifications. Standard controls include country-year effects, site-type dummies, coverage polynomials, number of establishments in company group. Dismissal Index taken from World Bank regulations database and represents an index of seven possible dismissal restrictions. Labour Regulation Index also taken from Word Bank database and represents an index of four main labor law provisions. Product Market regulation index taken from OECD database and uses the base year of 1998. Countries in sample include: Austria, Switzerland, Germany, Denmark, Spain, Finland, France, Great Britain, Italy, Netherlands, Norway, Poland, and Sweden.

TABLE I.7: ICT INVESTMENT EQUATIONS, EUROPEAN FIRMS 1999-2008.

Dependent Variable	(1) $\Delta\ln(ICT)_t$ 1-Year Lag	(2) $\Delta\ln(ICT/L)_t$ 2-Year Lag	(3) $\Delta\ln(K)_t$ 1-Year Lag	(4) $\Delta\ln(K)_t$ 2-Year Lag	(5) $\Delta\ln(ICT)_t$ GMMDiff	(6) $\Delta\ln(K)_t$ GMMDiff
$\Delta\ln(ICT)_{t-1}$	-0.057***				-0.058***	
Log change(ICT Investment)	(0.010)				(0.017)	
$\Delta\ln(ICT)_{t-2}$		-0.012				
		(0.010)				
$\Delta\ln(K)_{t-1}$			0.042***			0.071***
			(0.009)			(0.015)
$\Delta\ln(K)_{t-1}$				0.001		
				(0.009)		
$\Delta\ln(Y)_t$	0.248***	0.040*	0.327***	0.182***	0.077	0.374***
	(0.019)	(0.023)	(0.016)	(0.022)	(0.068)	(0.078)
$\Delta\ln(Y)^2_t$	-0.032	-0.089	-0.019	-0.013	1.094***	0.753***
	(0.045)	(0.063)	(0.044)	(0.064)	(0.108)	(0.206)
$(ecm\_ICT)_{t-1}$	0.463***				0.468***	
	(0.021)				(0.107)	
$(ecm\_ICT)_{t-2}$		0.014				
		(0.018)				
$(ecm\_K)_{t-1}$			0.359***			0.335***
			(0.013)			(0.082)
$(ecm\_K)_{t-2}$				0.162***		
				(0.014)		
Firm Fixed Effects	Yes	Yes	Yes	Yes	na	na
Number of Observations	36,310	24,985	36,310	24,270	21,445	21,445

Notes: * significant at 10%; ** significant at 5%; *** significant at 1%. Standard errors clustered by firm in parentheses below coefficients. ln(ICT) here is defined as the log number of PCs. Standard controls include country-year effects, site-type dummies, coverage polynomials, number of establishments in company group. Countries include: Austria, Switzerland, Germany, Denmark, Spain, Finland, France, Great Britain, Italy, Netherlands, Norway, Poland, and Sweden. ECM is the Error Correction Mechanism term.

TABLE I.8: EMPLOYMENT GROWTH EQUATIONS – EUROPEAN FIRMS, 1999-2008

Dependent Variable $\Delta \ln L$	*(A) No Accounts Controls* OLS (1)	+SIC4 (2)	Quintiles (3)	Amatech (4)	*(B) Plus AMATECH Controls* +Wages (5)	+Productivity (6)	Quintiles (7)
$(ICT / L)_{t-5}$	0.256***	0.292***		0.313***	0.320***	0.318***	
PCs per worker at (t-5) baseline	(0.008)	(0.009)		(0.011)	(0.011)	(0.011)	
Baseline Omitted category are firms in the lowest quintile of ICT intensity							
Quintile2 $(ICT / L)_{t-5}$			0.071***				0.069***
2nd Quintile PCs per worker at (t-5)			(0.006)				(0.009)
Quintile3 $(ICT / L)_{t-5}$			0.130***				0.123***
3rd Quintile PCs per worker at (t-5)			(0.007)				(0.010)
Quintile4 $(ICT / L)_{t-5}$			0.223***				0.208***
4th Quintile PCs per worker at (t-5)			(0.009)				(0.011)
Quintile5 $(ICT / L)_{t-5}$			0.347***				0.362***
(Highest) 5th Quintile PCs per worker at (t-5)			(0.011)				(0.013)
ln(Average Wage)					-0.036***	-0.046***	-0.044***
log(Wage Bill/Employment)					(0.011)	(0.012)	(0.012)
ln(Y/EMP)						0.010*	0.009
log(Sales/Employment)						(0.006)	(0.006)
SIC4 Industry Effects	No	Yes	Yes	Yes	Yes	Yes	Yes
Number of Observations	106,174	106,174	106,174	44,407	44,407	44,407	44,407

Notes: * significant at 10%; ** significant at 5%; *** significant at 1%. Standard errors cluster by sic4 industry in parentheses. All columns include site-type controls, year effects and country effects. Countries include Austria, Denmark, Finland, France, Germany, Ireland, Italy, Netherlands, Norway, Portugal, Spain, Sweden, Switzerland and the UK. The $(ICT / L)_{t-5}$ (PCs per worker) quintiles range from Quintile 1 as the lowest and Quintile 5 as the highest. The lowest Quintile 1 is the omitted category. Average Wage calculated as the total wage bill divided by number of employees (sourced from AMADEUS). Labour productivity defined as sales divided by the number of employees (also sourced from AMADEUS). Sample period includes 5-year differences ending in the years 2004-2008.

TABLE I.9: ESTABLISHMENT EXIT, PRODUCTIVITY AND TECHNOLOGY, EUROPEAN ESTABLISHMENTS 2000-2008.

	(A) No Accounts Controls			*(B) Plus Amatech Controls*			
Dependent Variable	OLS	+ SIC4	Quintiles	Amatech	+Wages	+Productivity	Quintiles
Pr(Exit)	(1)	(2)	(3)	(6)	(7)	(8)	(9)
$(ICT / L)_{(t=0)}$	0.007	-0.019***		-0.013*	-0.005	-0.003	
PCs per worker at baseline	(0.007)	(0.005)		(0.007)	(0.007)	(0.008)	
$\ln(L)_{(t=0)}$	-0.073***	-0.072***	-0.072***	-0.051***	-0.050***	-0.049***	-0.049***
log number of employees	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.003)	(0.003)
Quintile2 $(ICT / L)_{t-5}$			-0.026***				-0.021***
2nd Quintile PCs per worker at (t-5)			(0.006)				(0.008)
Quintile3 $(ICT / L)_{t-5}$			-0.038***				-0.031***
3rd Quintile PCs per worker at (t-5)			(0.006)				(0.007)
Quintile4 $(ICT / L)_{t-5}$			-0.027***				-0.018**
4th Quintile PCs per worker at (t-5)			(0.006)				(0.008)
Quintile5 $(ICT / L)_{t-5}$			-0.034***				-0.012
(Highest) 5th Quintile PCs per worker at (t-5)			(0.007)				(0.010)
Ln(WB/L)					-0.033***	-0.025**	-0.025**
log(Wage Bill/Employment)					(0.009)	(0.011)	(0.011)
ln(Y/EMP)						-0.014***	-0.013***
log(Sales/Employment)						(0.005)	(0.005)
SIC4 Industry Effects	No	Yes	Yes	Yes	Yes	Yes	Yes
Number of Observations	114,733	114,733	114,733	45,706	47,406	45,706	45,706

Notes: * significant at 10%; ** significant at 5%; *** significant at 1%. Standard errors cluster by sic4 industry in parentheses. All columns include site-type controls, year effects and country effects. Countries include Austria, Denmark, Finland, France, Germany, Ireland, Italy, Norway, Spain, Sweden, Switzerland and the UK. The mean exit rate over the 2000-2008 period is 0.23 (pooled across years, bases on all establishments alive in either 2000 or 2001). The $(ICT / L)_{t-5}$ (PCs per worker) quintiles range from Quintile 1 as the lowest and Quintile 5 as the highest. The lowest Quintile 1 is the omitted category.Average Wage calculated as the total wage bill divided by number of employees (sourced from AMADEUS). Labour productivity defined as sales divided by the number of employees (also sourced from AMADEUS). Sample includes all establishments existing in baseline years of 2000 and 2001. Exiting establishments are defined as all of those establishments who appeared in the Harte-Hanks survey in the years 2000 and 2001 but did not appear after 2005 (ie: no survey appearance in the years 2006,2007,2008).

TABLE I.10: COUNTRY HETEROGENEITY IN EMPLOYMENT GROWTH EQUATION, EUROPEAN FIRMS, 1999-2008.

	(1) $\Delta \ln L$ Baseline	(2) $\Delta \ln L$ SIC2	(3) $\Delta \ln L$ SIC3	(4) $\Delta \ln L$ SIC4
$(ICT/L)_{t-5}$	0.332***	0.339***	0.354***	0.356***
	(0.016)	(0.022)	(0.016)	(0.016)
France*$(ICT/L)_{t-5}$	-0.055**	-0.032	-0.031	-0.034
	(0.024)	(0.026)	(0.020)	(0.021)
Germany*$(ICT/L)_{t-5}$	-0.070***	-0.064**	-0.069***	-0.069***
	(0.023)	(0.028)	(0.022)	(0.021)
Italy*$(ICT/L)_{t-5}$	-0.117***	-0.120***	-0.125***	-0.124***
	(0.022)	(0.021)	(0.022)	(0.021)
Spain*$(ICT/L)_{t-5}$	-0.070***	-0.063**	-0.067**	-0.067***
	(0.026)	(0.030)	(0.026)	(0.026)
Austria*$(ICT/L)_{t-5}$	-0.125***	-0.108***	-0.110***	-0.109***
	(0.022)	(0.026)	(0.023)	(0.024)
Sweden*$(ICT/L)_{t-5}$	-0.087***	-0.071*	-0.061*	-0.058*
	(0.033)	(0.037)	(0.032)	(0.031)
Norway*$(ICT/L)_{t-5}$	-0.014	0.005	0.008	0.007
	(0.045)	(0.049)	(0.045)	(0.045)
Finland*$(ICT/L)_{t-5}$	-0.151***	-0.137***	-0.133***	-0.132***
	(0.028)	(0.038)	(0.030)	(0.030)
Denmark*$(ICT/L)_{t-5}$	-0.081***	-0.070**	-0.059*	-0.056*
	(0.030)	(0.031)	(0.032)	(0.031)
Switzerland*$(ICT/L)_{t-5}$	-0.163***	-0.145***	-0.149***	-0.146***
	(0.022)	(0.026)	(0.023)	(0.023)
Number of Observations	106,174	106,174	106,174	106,174

Notes: * significant at 10%; ** significant at 5%; *** significant at 1%. Standard errors cluster by sic4 industry in parentheses. All columns include site-type controls, year effects and country effects. Countries include Austria, Denmark, Finland, France, Germany, Ireland, Italy, Norway, Spain, Sweden, Switzerland and the UK.

TABLE I.11: COUNTRY HETEROGENIETY IN EMPLOYMENT GROWTH EQUATION – THE ROLE OF LABOUR AND PRODUCT MARKET REGULATION, EUROPEAN FIRMS 1999-2008.

	(1) $\Delta \ln L$	(2) $\Delta \ln L$	(3) $\Delta \ln L$	(4) $\Delta \ln L$	(5) $\Delta \ln L$	(7) $\Delta \ln L$
$(ICT/L)_{t-5}$	0.306***	0.332***	0.248***	0.278***	0.403***	0.420***
	(0.024)	(0.024)	(0.014)	(0.014)	(0.026)	(0.026)
$(ICT/L)_{t-5}$*Labour Regulation	-0.099**	-0.083**				
	(0.040)	(0.037)				
Labour Regulation Index	0.194***	0.180***				
	(0.032)	(0.027)				
$(ICT/L)_{t-5}$*Dismissal Index			0.006	0.017		
			(0.027)	(0.023)		
Dismissal Index			0.097***	0.089***		
			(0.022)	(0.016)		
$(ICT/L)_{t-5}$*Product Market Regulation					-0.074***	-0.066***
					(0.012)	(0.012)
Product Market Regulation Index					0.088***	0.078***
					(0.009)	(0.008)
SIC4 Fixed Effects	No	Yes	No	Yes		
Number of Observations	106,174	106,174	106,174	106,174	106,174	106,174

Notes: * significant at 10%; ** significant at 5%; *** significant at 1%. Standard errors cluster by sic4 industry in parentheses. All columns include site-type controls, year effects and country effects. Countries include Austria, Denmark, Finland, France, Germany, Ireland, Italy, Norway, Spain, Sweden, Switzerland and the UK. Dismissal Index taken from World Bank regulations database and represents an index of seven possible dismissal restrictions. Labour Regulation Index also taken from Word Bank database and represents an index of four main labor law provisions. Product Market regulation index taken from OECD database and uses the base year of 1998.

TABLE I.12: MACRO-DIFFUSION RESULTS FOR EUROPE, 1998-2008.

Dependent variable	PC Intensity (Number of PCs/Employees)									
	Austria	Germany	Denmark	Spain	France	UK	Norway	Sweden	EU	US
γ (Long term adopters)	0.547***	0.467***	0.805***	0.538***	0.565***	0.673***	0.743***	0.679***	0.609***	0.619***
β (Diffusion speed)	-2.657	1.348	0.314	13.612	1.057	0.896	-10.154	1.543	0.642***	0.306***
τ (Positioning parameter)	2008.9**	1996.8**	1995.7**	1997.9**	1996.7**	1997.1**	2008.0**	1997.6**	1997.2***	1995.9***
R^2	0.962	0.979	0.997	0.908	0.961	0.980	0.996	0.998	0.999	0.999
Number of Observations	10	11	10	11	11	11	10	10	9	9
PC Intensity in 2007	0.528	0.356	0.703	0.403	0.464	0.551	0.810	0.632	0.626	0.582
% Firms in ICT Using Industries	0.156	0.199	0.244	0.144	0.193	0.249	0.344	0.216	0.235	0.290
% Firms in ICT Producing Industries	0.038	0.068	0.083	0.032	0.061	0.088	0.073	0.062	0.038	0.070

Notes: * significant at 10%; ** significant at 5%; *** significant at 1%. Estimated by nonlinear least squares. Based on aggregated PC and employment information from the underlying AMATECH establishment-level panel. Aggregated variables calculated as weighted averages (ie: weighted by firm size). Data used covers the period 1998-2008. ICT-using and ICT-producing industries defined as per Van Ark et al (2002) definition.

TABLE I.13: MICROECONOMIC PC ADOPTION RESULTS FOR EUROPE, 2001-2008.

	(A) Manufacturing			(B) Services		
	(1)	(2)	(3)	(4)	(5)	(6)
	(PC/EMP)	(PC/EMP)	(PC/EMP)	(PC/EMP)	(PC/EMP)	(PC/EMP)
ln(EMP)	-0.045***	-0.051***	-0.094***	-0.058***	-0.061***	-0.088***
log(Employment)	(0.005)	(0.004)	(0.005)	(0.009)	(0.007)	(0.008)
(INF/EMP)	2.163***	1.733***	1.529***	0.822***	0.484***	0.449***
ICT Staff/Total Employment	(0.206)	(0.178)	(0.165)	(0.102)	(0.108)	(0.100)
ln(W)			0.081***			0.104***
log(Mean Wage)			(0.010)			(0.018)
ln(Y)			0.042***			0.026***
log(Mean Sales)			(0.003)			(0.006)
MNE			0.084***			0.095***
Multinational dummy			(0.006)			(0.018)
Region Fixed Effects	No	Yes	Yes	No	Yes	Yes
SIC4 Fixed Effects	No	Yes	Yes	No	Yes	Yes
Number of Observations	39,454	39,454	39,454	14,109	14,109	14,109

Notes: * significant at 10%; ** significant at 5%; *** significant at 1%. Standard errors clustered by SIC4 industry in parentheses. Countries include: Austria, Belgium, Czech Republic, Germany, Denmark, Spain, Finland, France, Great Britain, Hungary, Ireland, Italy, Norway, Poland, Sweden, and Slovakia. The ln(W) mean wage is calculated as the mean company wage across all available years; log turnover ln(Y) is also calculated as the mean over all years. Multinational dummy (MNE) is based on cases where the ultimate owner is not in the same country as the firm. Manufacturing defined as all industries between SIC2 = 20 and SIC2 = 39 (inclusive). Services defined as retail (SIC2=52-59); wholesale (SIC2=50-51); finance (SIC2=60-57); hospitality (SIC2=70-72); business services (SIC2=73) and repair services (SIC2=75-76).

TABLE I.14: CROSS-COUNTRY DIFFERENCES IN PC ADOPTION FOR EUROPE, 2005-2008.

	(1) All (PC/EMP)	(2) Manufacturing (PC/EMP)	(3) Services (PC/EMP)	(4) Retail & Wholesale (PC/EMP)	(5) Finance (PC/EMP)
ln(EMP)	-0.067***	-0.058***	-0.063***	-0.063***	-0.074***
log(Employment)	(0.003)	(0.003)	(0.005)	(0.005)	(0.008)
(INF/EMP)	0.410***	0.692***	0.494***	0.631***	0.197***
ICT Staff/Total Employment	(0.059)	(0.058)	(0.067)	(0.092)	(0.040)
Anglo Bloc	0.064*	0.195*	0.079	-0.073	0.425***
	(0.034)	(0.102)	(0.073)	(0.088)	(0.076)
Northern Bloc	0.252***	0.229	0.163***	0.064	0.329***
	(0.069)	(0.148)	(0.061)	(0.059)	(0.047)
Franco Bloc	0.057**	0.202***	0.310***	-0.083	0.229***
	(0.025)	(0.040)	(0.063)	(0.061)	(0.047)
Germanic Bloc	0.221***	0.167***	0.237***	0.212***	0.268***
	(0.025)	(0.027)	(0.064)	(0.068)	(0.051)
Southern Bloc	0.085**	0.064	0.020	-0.075	0.204*
	(0.039)	(0.042)	(0.058)	(0.067)	(0.106)
Region Fixed Effects	Yes	Yes	Yes	Yes	Yes
SIC4 Fixed Effects	Yes	Yes	Yes	Yes	Yes
Number of Observations	136,904	35,971	66,060	43,715	23,687

Notes: * significant at 10%; ** significant at 5%; *** significant at 1%. Standard errors clustered by SIC4 industry in parentheses. The years 2005-2008 are used because they have the most extensive country coverage in the database. Countries include: Austria, Belgium, Czech Republic, Germany, Denmark, Spain, Finland, France, Great Britain, Hungary, Ireland, Italy, Norway, Poland, Sweden, and Slovakia. Anglo Bloc defined as Great Britain and Ireland; Northern Bloc defined as Sweden, Norway, Finland and Denmark; Franco bloc defined as France and Belgium; Germanic Bloc defined as Germany and Austria; Southern Bloc defined as Italy and Spain. Omitted category is the Eastern Bloc of countries. Manufacturing defined as all industries between SIC2 = 20 and SIC2 = 39 (inclusive). Services defined as retail (SIC2=52-59); wholesale (SIC2=50-51); finance (SIC2=60-57); hospitality (SIC2=70-72); business services (SIC2=73) and repair services (SIC2=75-76).

TABLE I.15: DETERMINANTS OF SOFTWARE ADOPTION, EUROPEAN ESTABLISHMENTS, 1996-2007

	(A) Europe				(B) US			
	Pr(DATA)	Pr(DATA)	Pr(ERP)	Pr(ERP)	Pr(DATA)	Pr(DATA)	Pr(ERP)	Pr(ERP)
Variables	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
ln(L)	0.631***	0.631***	0.240***	0.240***	0.752***	0.752***	0.349***	0.348***
log(Employment)	(0.047)	(0.047)	(0.041)	(0.041)	(0.027)	(0.027)	(0.013)	(0.013)
(Number of PCs/Employees)$_{t-1}$	0.447***	0.443***	0.030	0.030	1.688***	1.693***	0.535***	0.532***
PC Intensity$_{t-1}$ (lagged)	(0.161)	(0.161)	(0.034)	(0.034)	(0.102)	(0.103)	(0.048)	-0.048
(ICT Staff/Employees)$_{t-1}$	1.944***	1.926***	0.548*	0.544*		-0.168		0.303***
ICT Staff Intensity$_{t-1}$ (lagged)	(0.528)	(0.530)	(0.298)	(0.299)		(0.111)		(0.079)
ICT-Using Industry		-0.236***		0.038		0.010		-0.059
Dummy for ICT-using industry		(0.066)		(0.088)		(0.082)		(0.066)
ICT-Producing Industry		0.150**		0.023		-0.000***	-0.000***	-0.000***
Dummy for ICT-producing industry		(0.063)		(0.083)		(0.000)	(0.000)	(0.000)
GDP per capita	-0.000	-0.000	-0.000	-0.000	-0.000***	9.879***	6.333***	6.331***
Regional NUTS1 GDP	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.657)	(0.364)	(0.364)
(TECH / N^f)$_{NUTS1}$ (T-1)	3.485***	3.484***	2.585***	2.587***	9.877***	-0.000	-0.001***	-0.001***
Lagged regional NUTS1 technology penetration	(0.675)	(0.674)	(0.564)	(0.564)	(0.656)	(0.000)	(0.000)	(0.000)
(N^f)$_{NUTS1}$	-0.000	-0.000	-0.000	-0.000	-0.000	-6.155***	-2.544***	-2.988***
Lagged number of firms sampled	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.502)	(0.330)	(0.346)
Industry Dummies	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Country Dummies	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Region Dummies (NUTS1)	No	Yes	No	Yes	No	Yes	No	Yes
Number of Observations	152,078	152,078	151,000	151,000	124,096	124,096	124,096	124,096
No. Clusters	76	76	73	73	39	39	39	39

Notes: * significant at 10%; ** significant at 5%; *** significant at 1%. Logit estimation with robust standard errors in parentheses. Estimated for the years 2000-2007 in Europe and 1996-2007 for the United States. Sample covers all manufacturing industries SIC2 = 20-39. Industry SIC4, country and regional dummies included in all specifications. Countries in European sample include: Austria, Belgium, Czech Republic, Germany, Denmark, Spain, Finland, France, UK, Hungary, Ireland, Netherlands, Norway, Poland, Sweden, Slovakia and Switzerland.

TABLE I.16: HAZARD RATE MODELS OF SOFTWARE ADOPTION

Dependent Variable	(A) *General Software Types* DATA (1)	DATA (2)	ERP (3)	ERP (4)	(B) *Specific ERP Types* HRM (1)	HRM (2)	CRM (3)	CRM (4)
ln(L)	0.012	0.122^{***}	-0.014	-0.006	0.009	-0.055^{*}	0.098^{***}	0.067^{**}
log(Employment)	(0.038)	(0.033)	(0.033)	(0.033)	(0.030)	(0.028)	(0.030)	(0.028)
(Number of PCs/Employees)$_{t-1}$	0.002	0.002	-0.003	-0.003	-0.008	-0.002	0.002	0.001
PC Intensity$_{t-1}$ (lagged)	(0.002)	(0.002)	(0.009)	(0.010)	(0.018)	(0.009)	(0.007)	(0.006)
(ICT Staff/Employees)$_{t-1}$	0.676	0.706^{*}	-0.346	-0.193	-0.140	-0.231	0.019	0.031
ICT Staff Intensity$_{t-1}$ (lagged)	(0.517)	(0.426)	(0.515)	(0.508)	(0.366)	(0.400)	(0.367)	(0.387)
Time	-0.000^{***}	-0.000^{***}	-0.000^{***}	-0.000^{***}	-0.000^{***}	-0.000^{***}	-0.000^{***}	-0.000^{***}
Time dummy	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
GDP per capita	-1.754^{***}	-1.494^{***}	-3.706^{***}	-3.663^{***}	-2.842^{***}	1.007^{***}	-0.951	3.403^{***}
Regional NUTS1 GDP	(0.380)	(0.275)	(0.461)	(0.461)	(0.531)	(0.294)	(1.102)	(0.843)
$(TECH / N^{f})_{NUTS1}$	4.192^{***}	-0.967^{***}	2.692^{***}	2.628^{***}	-6.278^{***}	-5.042^{***}	-4.140^{***}	-6.446^{***}
Regional NUTS1 technology penetration	(0.496)	(0.272)	(0.437)	(0.400)	(0.489)	(0.212)	(0.429)	(0.220)
Constant								
Industry Fixed Effects	Yes	No	Yes	No	Yes	No	Yes	No
Country Fixed effects	Yes	No	Yes	No	Yes	No	Yes	No
P	1.297^{***}	0.809^{***}	1.328^{***}	1.326^{***}	1.459^{***}	1.149^{***}	1.587^{***}	1.206^{***}
	(0.034)	(0.042)	(0.030)	(0.030)	(0.029)	(0.030)	(0.027)	(0.031)
Number of Observations	2,417	2,417	3,868	3,868	16,959	16,959	19,638	19,638

Notes: * significant at 10%; ** significant at 5%; *** significant at 1%. Weibull estimation with robust standard errors in parentheses. Estimated for the years 2000-2007, sample covers all manufacturing industries SIC2 = 20-39. Industry SIC4 and country dummies included in all specifications. Countries include: Austria, Belgium, Czech Republic, Germany, Denmark, Spain, Finland, France, UK, Hungary, Ireland, Luxemburg, Netherlands, Norway, Poland, Sweden, Slovakia and Switzerland.

TABLE I.17: THE “DIGITAL DIVIDE”: REGIONAL DETERMINANTS OF PC INTENSITY, 1999-2008.

Dependent Variable (Number PCs/ Employees)	(A) Germany (1) PC/EMP	(2) PC/EMP	(3) PC/EMP
Baden Württemberg	-0.033***	-0.235***	-0.143*
	(0.006)	(0.074)	(0.075)
Bavaria	-0.004	-0.269**	-0.193*
	(0.004)	(0.094)	(0.096)
Brandeburg	-0.180***	-0.334***	-0.202**
	(0.004)	(0.063)	(0.069)
Bremen	-0.007*	-0.251**	-0.203
	(0.004)	(0.113)	(0.120)
Hamburg	0.127***	0.063	0.022
	(0.003)	(0.063)	(0.068)
Hesse	0.072***	-0.104	-0.097
	(0.002)	(0.064)	(0.068)
Mecklenburg Vorpommern	-0.133***	-0.305***	-0.194**
	(0.005)	(0.071)	(0.077)
Lower Saxony	-0.035***	-0.374***	-0.294**
	(0.004)	(0.111)	(0.115)
North Rhine Westphalia	-0.018***	-0.253**	-0.190*
	(0.003)	(0.096)	(0.101)
Rhineland Palatinate	-0.024***	-0.263**	-0.204*
	(0.003)	(0.091)	(0.096)
Saarland	-0.068***	-0.372**	-0.321**
	(0.004)	(0.128)	(0.132)
Saxony	-0.104***	-0.291***	-0.172**
	(0.003)	(0.057)	(0.062)
Saxony Anhalt	-0.080***	-0.313***	-0.208**
	(0.004)	(0.086)	(0.093)
Schleswig Holstein	-0.069***	-0.301**	-0.235*
	(0.004)	(0.103)	(0.111)
Thuringia	-0.112***	-0.286***	-0.164**
	(0.004)	(0.057)	(0.060)
Region Controls	No	Yes	Yes
SIC4 Fixed effects	No	No	Yes
Number of Observations	20,964	20,964	20,964

	(B) United Kingdom (1) PC/EMP	(2) PC/EMP	(3) PC/EMP
North_East	-0.384***	-0.269***	-0.128***
	(0.012)	(0.052)	(0.037)
North_West	-0.301***	-0.236***	-0.120***
	(0.009)	(0.048)	(0.035)
Yorkshire	-0.332***	-0.230***	-0.097**
	(0.009)	(0.049)	(0.034)
East_Midlands	-0.313***	-0.236***	-0.109**
	(0.010)	(0.055)	(0.039)
West_Midlands	-0.323***	-0.245***	-0.107**
	(0.009)	(0.053)	(0.037)
East_Eng	-0.193***	-0.176**	-0.083
	(0.010)	(0.070)	(0.055)
South_East	-0.099***	-0.096**	-0.036
	(0.009)	(0.041)	(0.035)
South_West	-0.228***	-0.174***	-0.086**
	(0.010)	(0.040)	(0.033)
Wales	-0.392***	-0.296***	-0.177***
	(0.013)	(0.040)	(0.027)
Scotland	-0.291***	-0.248***	-0.138***
	(0.010)	(0.016)	(0.014)
Northern_Ireland	-0.405***	-0.319***	-0.180***
	(0.017)	(0.039)	(0.024)
Region Controls	No	Yes	Yes
SIC4 Fixed effects	No	No	Yes
Number of Observations	37,006	37,006	37,006

	(C) France (1) PC/EMP	(2) PC/EMP	(3) PC/EMP
Ile_de_France	0.268***	0.203***	0.104**
	(0.004)	(0.037)	(0.040)
NordPasdeCalais	0.006***	0.070***	0.068***
	(0.001)	(0.013)	(0.013)
East	-0.013***	-0.018*	-0.006
	(0.002)	(0.008)	(0.010)
West	-0.007***	0.001	-0.001
	(0.001)	(0.012)	(0.014)
South West	0.008***	-0.048**	-0.050**
	(0.002)	(0.014)	(0.015)
Centre East	0.031***	-0.042*	-0.061**
	(0.001)	(0.019)	(0.019)
Mediterranean	0.048***	0.065***	0.036*
	(0.003)	(0.012)	(0.018)
Region Controls	No	Yes	Yes
SIC4 Fixed effects	No	No	Yes
Number of Observations	42,500	42,500	42,500

Notes: * significant at 10%; ** significant at 5%; *** significant at 1%. Standard errors clustered by NUTS1 region in parentheses. All columns include controls for site-type, establishment size (log(employment)) and year fixed effects. The regional controls included in column (2) of each panel are private sector R&D expenditure (as % of regional GDP), proportion of labour force with secondary education; and proportion of labour force with tertiary education. Both sets of regional variables obtained from the OECD regional database. The omitted case for Germany is Berlin; omitted case for the UK is London, and omitted case for France is the Parisien basin.

TABLE I.18: GEOGRAPHICAL CONCENTRATION, ICT AND INDUSTRY CHARACTERISTICS, EVIDENCE FROM THE UK ARD, 1998-2006.

Dependent Variable	(A) Period I – 1998-2001				(B) Period II – 2002-2006			
S = Spatial Concentration	Manuf	Services	Manuf	Services	Manuf	Services	Manuf	Services
ICT	-0.069***	0.047***	-0.077***	0.015	-0.076***	0.037**	-0.082***	0.0024
PC Intensity	0.025	0.016	0.029	0.040	0.024	0.018	0.026	0.020
Transport			0.059	0.50**			0.033	0.63
Share of Inputs from Transport			0.15	0.25			0.10	0.42
Manufacturing			-0.0084	0.49*			-0.0048	0.65
Share of Inputs from Manufacturing			0.028	0.26			0.032	0.44
Services			0.10	0.45*			0.094	0.62
Share of Inputs from Services			0.082	0.24			0.071	0.40
Own IO			0.035	0.065			0.011	0.057
Share of Inputs from Manufacturing			0.022	0.050			0.018	0.039
EG			0.11	1.06*			0.10	1.47
			0.071	0.57			0.070	0.91
Skill			0.017	0.100			0.017	0.082**
Share of Degree Educated Workers			0.038	0.060			0.025	0.038
Number of Observations	90	86	85	73	88	88	84	75
R-squared	0.104	0.031	0.159	0.082	0.139	0.031	0.181	0.096

Notes: ***, ** and * indicate significance at the 1%, 5% and 10% levels, respectively. Standard errors reported below coefficients are robust to arbitrary heteroscedasticity. Spatial Concentration measure *S* is constructed as the Ellison-Glaeser index.

TABLE I.19: IV ESTIMATES FOR GEOGRAPHICAL CONCENTRATION AND ICT, EVIDENCE FROM THE UK ARD, 1998-2006

	(A) Period I – 1998-2001				(B) Period II – 2002-2006			
S = Spatial Concentration	Manuf	Services	Manuf	Services	Manuf	Services	Manuf	Services
ICT	-0.066***	0.14**	-0.084***	0.085	-0.056*	0.14**	-0.099***	0.15
PC Intensity	0.020	0.061	0.029	0.12	0.029	0.071	0.031	0.16
Transport			0.052	0.55**			0.040	0.49
Share of Inputs from Transport			0.14	0.27			0.097	0.49
Manufacturing			-0.0081	0.57*			-0.0024	0.55
Share of Inputs from Manufacturing			0.026	0.31			0.032	0.49
Services			0.10	0.46*			0.098	0.44
Share of Inputs from Services			0.078	0.25			0.065	0.49
Own IO			0.035*	0.089			0.011	0.050
Share of Inputs from Manufacturing			0.020	0.085			0.017	0.038
EG			0.11*	1.10*			0.10	1.04
			0.067	0.59			0.067	1.17
Skill			0.024	0.13**			0.030	0.062
Share of Degree Educated Workers			0.045	0.063			0.035	0.075
Number of Observations	88	82	84	69	88	84	84	71

Notes: ***, ** and * indicate significance at the 1%, 5% and 10% levels, respectively. Standard errors reported below coefficients are robust to arbitrary heteroscedasticity. Spatial Concentration measure *S* is constructed as the Ellison-Glaeser index.

TABLE I.20: FIXED EFFECTS AND IV ESTIMATES FOR GEOGRAPHICAL CONCENTRATION AND ICT, EVIDENCE FROM THE UK ARD, 1998-2006

Dependent Variable	OLS				IV			
S = Spatial Concentration	Manuf	Services	Manuf	Services	Manuf	Services	Manuf	Services
ICT	-0.021	-0.0040	-0.027**	0.0023	0.47	0.084	-0.069	0.022
PC Intensity	0.013	0.011	0.011	0.014	0.74	0.10	0.14	0.060
Transport			-0.096	0.59**			-0.080	0.41
Share of Inputs from Transport			0.11	0.22			0.19	0.25
Manufacturing			-0.032**	0.16			-0.024	-0.023
Share of Inputs from Manufacturing			0.016	0.34			0.033	0.39
Services			-0.018	0.19			-0.028	0.038
Share of Inputs from Services			0.015	0.30			0.020	0.33
Own IO			0.029	-0.073			0.028	-0.092
Share of Inputs from Manufacturing			0.029	0.064			0.039	0.072
EG			0.0031	0.078			-0.15	-0.19
			0.14	0.46			0.52	0.64
Skill			0.019	-0.045**			0.013	-0.061
Share of Degree Educated Workers			0.015	0.022			0.019	0.050
Observations	178	174	169	148	176	164	162	136
Number of groups	90	88	88	76	88	82	81	68

Notes: ***, ** and * indicate significance at the 1%, 5% and 10% levels, respectively. Standard errors reported below coefficients are robust to arbitrary heteroscedasticity. The columns labelled OLS report standard fixed effects estimates. The columns labelled IV instrument using US ICT.

TABLE I.21: DISTANCE AND STATE-BORDER EFFECTS ON CITATIONS

Dependent variable: Citation Dummy (Marginal Effects)

	(1)	(1)	(2)	(4)	(5)	(6)
University cited patents:	All	All	All	All	Cites received ≤ Median	Cites received > Median
Dummy for Intra-State Citation		0.225*** (0.005)	0.104*** (0.003)	0.097*** (0.009)	0.091*** (0.015)	0.097*** (0.011)
log(Distance), Miles	-0.045*** (0.001)		-0.024*** (0.002)			
Matched on four-digit IPC	0.105*** (0.003)	0.104*** (0.003)	0.104*** (0.003)	0.103*** (0.003)	0.128*** (0.004)	0.098*** (0.003)
Dummy for 25 ≤ Distance < 50				-0.220*** (0.011)	-0.290*** (0.018)	-0.202*** (0.012)
Dummy for 50 ≤ Distance < 100				-0.306*** (0.011)	-0.391*** (0.014)	-0.286*** (0.013)
Dummy for 100 ≤ Distance < 150				-0.305*** (0.011)	-0.393*** (0.014)	-0.285*** (0.013)
Dummy for 150 ≤ Distance < 250				-0.296*** (0.010)	-0.391*** (0.013)	-0.275*** (0.012)
Dummy for 250 ≤ Distance < 500				-0.308*** (0.009)	-0.412*** (0.013)	-0.284*** (0.011)
Dummy for 500 ≤ Distance < 1000				-0.312*** (0.010)	-0.425*** (0.015)	-0.288*** (0.012)
Dummy for Distance ≥ 1000				-0.292*** (0.011)	-0.439*** (0.018)	-0.263*** (0.013)
R^2	0.021	0.022	0.023	0.029	0.054	0.025
Observations	258,966	258,966	258,966	258,966	42,364	216,602

Notes: This table reports the results of Probit regressions relating the probability of citing a university patent and the distance of the citing inventor from the cited university. All regressions include complete sets of university, state, cited and citing grant year dummies. We also include a set of twenty dummies for observations where both citing and cited inventors reside in the following cities: Boston, Raleigh, San Diego, Stanford and Austin. Estimated standard errors (in brackets) are clustered by cited patents (robust to arbitrary heteroskedasticity and within cluster serial correlation). * significant at 10%; ** significant at 5%; *** significant at 1%.

TABLE I.22: EFFECTS OF PRIVATE OWNERSHIP AND POLICIES ON STATE-BORDER EFFECTS.

Dependent variable: Citation Dummy (Marginal Effects)

	(1)	(2)	(3)	(4)	(5)	(6)
University cited patents:	Private	Public	All	All	Cited Grant Year≤1993	Cited Grant Year>1993
Dummy for Intra-State Citation	0.076*** (0.012)	0.114*** (0.015)	0.184*** (0.013)	0.168*** (0.016)	0.179*** (0.023)	0.157*** (0.021)
Dummy for Intra-State Citation × Dummy for Private			-0.089*** (0.014)	-0.046*** (0.018)	-0.060*** (0.027)	-0.035* (0.023)
Dummy for Intra-State Citation × TechPole			-0.006*** (0.001)	-0.006*** (0.001)	-0.006*** (0.002)	-0.007*** (0.002)
Dummy for Intra-State Citation × Number of State Constraints				0.019*** (0.006)	0.006 (0.011)	0.028*** (0.008)
Dummy for Intra-State Citation × Weak Local Objectives				-0.052*** (0.014)	-0.027* (0.020)	-0.071*** (0.018)
Dummy for Intra-State Citation × Performance-Based Pay				-0.018 (0.015)	-0.005 (0.023)	-0.028* (0.019)
Dummy for Intra-State Citation × Dummy for Land Grant				-0.003 (0.016)	0.003 (0.024)	-0.005 (0.022)
Matched on four-digit IPC	0.098*** (0.003)	0.108*** (0.004)	0.103*** (0.003)	0.168*** (0.016)	0.107*** (0.004)	0.010*** (0.003)
Dummy for 25 ≤ Distance < 50	-0.204*** (0.012)	-0.287*** (0.016)	-0.206*** (0.019)	-0.221*** (0.020)	-0.193*** (0.036)	-0.249*** (0.022)
Dummy for 50 ≤ Distance < 100	-0.289*** (0.014)	-0.367*** (0.014)	-0.331*** (0.015)	-0.334*** (0.015)	-0.306*** (0.025)	-0.358*** (0.018)
Dummy for 100 ≤ Distance < 150	-0.274*** (0.015)	-0.381*** (0.013)	-0.328*** (0.017)	-0.332*** (0.016)	-0.297*** (0.026)	-0.363*** (0.019)
Dummy for 150 ≤ Distance < 250	-0.274*** (0.013)	-0.360*** (0.013)	-0.292*** (0.013)	-0.298*** (0.013)	-0.277*** (0.020)	-0.317*** (0.016)
Dummy for 250 ≤ Distance < 500	-0.267*** (0.012)	-0.398*** (0.012)	-0.329*** (0.012)	-0.335*** (0.011)	-0.305*** (0.018)	-0.363*** (0.014)
Dummy for 500 ≤ Distance < 1000	-0.278*** (0.013)	-0.407*** (0.015)	-0.323*** (0.012)	-0.330*** (0.011)	-0.303*** (0.017)	-0.355*** (0.015)
Dummy for Distance ≥ 1000	-0.251*** (0.014)	-0.403*** (0.017)	-0.307*** (0.012)	-0.314*** (0.012)	-0.277*** (0.017)	-0.350*** (0.016)
Interactions between Distance Dummies and Dummy for Private (7)	No	No	Yes	Yes	Yes	Yes
			χ^2=16.7***	χ2=14.6**	χ2=6.88	χ2=23.89***
R^2	0.025	0.037	0.030	0.030	0.026	0.036
Observations	139,720	119,246	258,966	258,966	123,528	116,010

Notes: This table reports Probit regressions relating the probability of citing a university patent and the distance of the citing inventor from the cited university. All regressions include complete sets of university, state, cited and citing grant year dummies. We also include a set of twenty dummies for observations where both citing and cited inventors reside in the following cities: Boston, Raleigh, San Diego, Stanford and Austin. TechPole is a measure of high-tech density (to proxy the local demand for licensing), constructed by the Milken Institute (Devol and Wong, 1999). The index ranges from zero to a maximum value of about 23 for Silicon Valley. State-Constraints is the number of state government constraints that the university reports as moderately or very important (based on six different constraints in the survey). Local Objectives meaures the weight the university attaches to local/regional development objectives in its licensing activity. Dummy for perfomance-based pay is one for universities using bonus pay in their technology licensing offices. Estimated standard errors (in brackets) are clustered by cited patents (robust to arbitrary heteroskedasticity and within cluster serial correlation). * significant at 10%; ** significant at 5%; *** significant at 1%.

TABLE I.23: DISTANCE AND STATE-BORDER EFFECTS ON CITATIONS, BY TECHNOLOGY AREAS

	Dependent variable: Citation Dummy (Marginal Effects)								
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Technology area of cited patent:	*Biotechnology*	*Chemicals*	*Electronics*	*Information Technology*	*Metallurgy*	*Mechanical and Engineering*	*Medical Equipment*	*Pharmaceutical*	*Physics*
Dummy for Intra-State Citation	0.266***	0.247***	0.161***	0.111***	0.076	0.175***	0.123***	0.259***	0.182***
	(0.040)	(0.028)	(0.035)	(0.037)	(0.060)	(0.045)	(0.032)	(0.033)	(0.031)
Dummy for Intra-State Citation × Dummy for Private	-0.094**	-0.153***	-0.145***	-0.006	-0.047	-0.072	-0.045	-0.060	-0.131***
	(0.046)	(0.033)	(0.036)	(0.042)	(0.066)	(0.050)	(0.034)	(0.041)	(0.032)
Dummy for Intra-State Citation × TechPole	-0.001	-0.001	-0.004*	-0.010***	-0.007	-0.010**	-0.002	-0.014***	-0.003
	(0.003)	(0.003)	(0.002)	(0.002)	(0.066)	(0.003)	(0.003)	(0.003)	(0.002)
Matched on four-digit IPC	0.193***	0.113***	0.078***	0.055***	0.158***	0.141***	0.114***	0.064***	0.158***
	(0.016)	(0.008)	(0.006)	(0.007)	(0.018)	(0.012)	(0.007)	(0.007)	(0.006)
Dummy for 25 ≤ Distance < 50	-0.220***	-0.266***	-0.230***	-0.141***	-0.277***	-0.251***	-0.278***	-0.330***	-0.151***
	(0.035)	(0.026)	(0.025)	(0.034)	(0.051)	(0.043)	(0.026)	(0.024)	(0.025)
Dummy for 50 ≤ Distance < 100	-0.286***	-0.354***	-0.379***	-0.188***	-0.422***	-0.262***	-0.306***	-0.402***	-0.330***
	(0.039)	(0.024)	(0.022)	(0.038)	(0.039)	(0.048)	(0.028)	(0.025)	(0.024)
Dummy for 100 ≤ Distance < 150	-0.242***	-0.367***	-0.342***	-0.225***	-0.330***	-0.308***	-0.296***	-0.405***	-0.297***
	(0.046)	(0.022)	(0.029)	(0.043)	(0.055)	(0.056)	(0.032)	(0.026)	(0.027)
Dummy for 150 ≤ Distance < 250	-0.277***	-0.372***	-0.312***	-0.160***	-0.366***	-0.343***	-0.287***	-0.372***	-0.307***
	(0.033)	(0.022)	(0.027)	(0.035)	(0.046)	(0.036)	(0.028)	(0.029)	(0.022)
Dummy for 250 ≤ Distance < 500	-0.238***	-0.375***	-0.334***	-0.187***	-0.431***	-0.329***	-0.312***	-0.377***	-0.294***
	(0.038)	(0.024)	(0.025)	(0.033)	(0.036)	(0.034)	(0.027)	(0.032)	(0.021)
Dummy for 500 ≤ Distance < 1000	-0.242***	-0.382***	-0.338***	-0.195***	-0.455***	-0.345***	-0.302***	-0.415***	-0.320***
	(0.040)	(0.026)	(0.027)	(0.034)	(0.043)	(0.040)	(0.029)	(0.032)	(0.023)
Dummy for Distance ≥ 1000	-0.202***	-0.347***	-0.349***	-0.200***	-0.419***	-0.359***	-0.268***	-0.354***	-0.318***
	(0.041)	(0.031)	(0.032)	(0.035)	(0.056)	(0.043)	(0.032)	(0.039)	(0.025)
R^2	0.052	0.053	0.025	0.001	0.041	0.038	0.023	0.050	0.040
Observations	18,087	31,096	31,937	27,299	7,166	13,530	43,326	21,780	38,471

Notes: This table reports the results of Probit regressions relating the probability of citing a university patent and the distance of the citing inventor from the cited university. All regressions include complete sets of university, state, cited and citing grant year dummies. We also include a set of twenty dummies for observations where both citing and cited inventors reside in the following cities: Boston, Raleigh, San Diego, Stanford and Austin. Estimated standard errors (in brackets) are clustered by cited patents (robust to arbitrary heteroskedasticity and within cluster serial correlation). * significant at 10%; ** significant at 5%; *** significant at 1%.

TABLE I.24: ICT AND THE PUBLIC SECTOR IN EUROPE, DESCRIPTIVE STATISTICS.

(A) ICT Intensity (PCs/Employees) Across Sectors

	Mean	Min	Max	Standard deviation	Observations
Manufacturing	0.65	0.00	490.00	2.37	182048
Services	1.18	0.00	506.00	4.76	66942
Public Sector	1.32	0.00	1000.00	7.12	65653

(B) Public Sector ICT Intensity in Detail

	Mean	Min	Max	Standard deviation	Observations
Health Services (SIC 80)	0.72	0.00	465.00	5.49	15728
Educational Services (SIC 82)	2.26	0.00	1000.00	11.91	12807
Social Services (SIC 83)	1.02	0.00	52.50	1.77	3770
Executive, Legislative and General Government (SIC 91)	1.33	0.00	335.00	5.40	21301
Justice, Public Order and Safety (SIC 92)	1.91	0.00	376.00	14.31	1489
Public Finance, Taxation and Monetary Policy (SIC 93)	1.21	0.00	50.00	1.89	1188
Administration of Human Resource Programs (SIC 94)	1.05	0.00	200.00	3.58	4453
Administration of Environmental Quality and Housing Programs (SIC 95)	1.01	0.00	47.24	1.66	2669
Administration of Economic Programs (SIC 96)	1.15	0.01	42.50	2.07	1703
National Security and International Affairs (SIC 97)	1.41	0.00	31.67	2.78	545

(B) ICT Intensity (PCs/Employees) Across Sectors

	Manufacturing	Services	Public Sector	Total
Eastern Europe	0.51	1.06	1.00	0.70
Northern Europe	0.79	1.24	1.75	1.08
Southern Europe	0.53	1.05	1.01	0.71
Western Europe	0.62	1.19	1.24	0.89
Total	0.65	1.18	1.32	0.90

Notes: * significant at 10%; ** significant at 5%; *** significant at 1%. Standard errors clustered by SIC4 industry in parentheses. The years 2005-2008 are used because they have the most extensive country coverage in the database. Countries include: Austria, Belgium, Czech Republic, Germany, Denmark, Spain, Finland, France, Great Britain, Hungary, Ireland, Italy, Norway, Poland, Sweden, and Slovakia.

TABLE I.25: COMPLEMENTARITY BETWEEN PUBLIC AND PRIVATE ICT INVESTMENT, EUROPEAN FIRMS, 1999-2008.

	(1)	(2)	(3)
Dependent Variables	Log(Sales/Emp)	Log(Sales/Emp)	Log(Sales/Emp)
ln(C/L) ICT capital per employee	0.1644*** (0.0052)	0.1411*** (0.0169)	0.1397*** (0.0287)
ln(K/L) Non-ICT Capital per employee	0.1834*** (0.0044)	0.1836*** (0.0044)	0.1836*** (0.0044)
ln(L) Labour	0.0067 (0.0049)	0.0064 (0.0049)	0.0064 (0.0049)
ln(Cpublic/L)*ln(C/L) ICT Capital per employee*Public sector ICT capital per employee		0.0126 (0.0154)	0.0211 (0.0198)
GDP per capital*ln(C/L)	No	No	Yes
SIC4 Fixed Effects	Yes	Yes	Yes
Observations	79,984	79,984	79,984

Notes: Main AMTECH sample of Harte-Hanks establishment-level data matched to AMADEUS company accounts. Countries include: Austria, Switzerland, Germany, Denmark, Spain, Finland, France, Great Britain, Italy, Netherlands, Norway, Poland and Sweden. Branch-site and HQ-site represent the proportion of production and HQ type establishments per company (where establishments are weighted by employment).

TABLE I.26: CHANGES IN PRODUCER PRICES – EUROPE AND THE US, 1996-2005.

(A) Europe, 2-digit industry

	2-Year Changes		4-Year Changes		5-Year Changes	
	(1)	(2)	(3)	(4)	(5)	(6)
	$\Delta \ln PPI$	$\Delta \ln PPI$	$\Delta \ln PPI$	$\Delta \ln PPI$	$\Delta \ln PPI$	$\Delta \ln PPI$
ΔIMP Change in Chinese Import Penetration	-0.471** (0.228)	-0.473** (0.230)	-0.487* (0.253)	-0.482* (0.256)	-0.824* (0.451)	-0.803** (0.399)
ΔICT Change in industry ICT		-0.032 (0.022)		-0.063** (0.031)		
ICT-Producing ICT Producing Industries						-0.165** (0.066)
Years	1996-2005	1996-2005	1996-2005	1996-2005	1996-2005	1996-2005
Number of Observations	669	669	440	440	585	585

(B) US, 4-digit industry

	2-Year Changes		4-Year Changes		5-Year Changes	
	(1)	(2)	(3)	(4)	(5)	(6)
	$\Delta \ln PPI$	$\Delta \ln PPI$	$\Delta \ln PPI$	$\Delta \ln PPI$	$\Delta \ln PPI$	$\Delta \ln PPI$
ΔIMP Change in Chinese Import Penetration	-0.340 (0.260)	-0.345 (0.261)	-0.273 (0.212)	-0.274 (0.211)	-0.315** (0.143)	-0.277** (0.140)
ΔICT Change in industry ICT		-0.043** (0.019)		-0.032* (0.019)		
ICT-Producing ICT Producing Industries						-0.137*** (0.044)
Years	1996-2005	1996-2005	1996-2005	1996-2005	1996-2005	1996-2005
Number of Observations	2906	2906	2894	2894	2195	2195

Notes: Standard errors clustered by industry in parentheses. The European producer price data is defined at the 2-digit level and taken from the Eurostat industry database. Countries included are: Austria, Germany, Denmark, France, Finland, the UK, Norway and Sweden. US produce prices data taken from the NBER Manufacturing Industry database where the producer measure is defined the value of shipments deflators Both panels (A) and (B) use ICT data taken from from the Harte-Hanks establishment databases for the US and Europe. The ΔICT variables is defined as the change log PCs per person (weighted by employment) at the industry level. The import penetration measure ΔIMP represents the value of Chinese imports as a share of total world imports per country-industry-year cell. The dummy for the ICT-producing industries follows the O'Mahoney and Van Ark(2002) definition and is set to cover all SIC2 industries from 35-38 i the 2-digit case.

TABLE I.27: CHANGES IN EUROPEAN CONSUMER PRICES, 1996-2008.

	(1) $\Delta \ln RPI$	(2) $\Delta \ln RPI$	(3) $\Delta \ln RPI$	(4) $\Delta \ln RPI$	(5) $\Delta \ln RPI$
BOOKS	-0.004	-0.004	-0.004	-0.004	0.016
	(0.007)	(0.007)	(0.006)	(0.006)	(0.031)
RECORDS	-0.104***	-0.104***	-0.104***	-0.104***	-0.132**
	(0.011)	(0.011)	(0.011)	(0.011)	(0.060)
ELECTRO	-0.275***	-0.275***	-0.275***	-0.275***	-0.479**
	(0.031)	(0.031)	(0.031)	(0.031)	(0.200)
NEWS	0.034***	0.034***	0.034***	0.034***	0.074*
	(0.009)	(0.009)	(0.009)	(0.009)	(0.039)
PMR		0.013**	0.003	0.003	-0.001
		(0.006)	(0.008)	(0.008)	(0.007)
BAND		-0.003***	-0.001	-0.001	-0.001
		(0.001)	(0.001)	(0.001)	(0.001)
ln(GDP)			-0.058***	-0.058***	-0.058***
			(0.021)	(0.021)	(0.021)
BOOKS*BAND					-0.000
					(0.003)
NEWS*BAND					0.001
					(0.003)
RECORDS*BAND					0.005
					(0.005)
ELECTRO*BAND					0.003
					(0.013)
BOOKS*PMR					-0.013
					(0.018)
NEWS*PMR					-0.028
					(0.029)
RECORDS*PMR					0.009
					(0.038)
ELECTRO*PMR					0.128
					(0.111)
Number of Observations	20,272	20,272	20,272	20,272	20,272

Notes: Standard errors clustered by product category in parentheses. Countries include: Austria, Belgium, Germany, Denmark, Spain, Finland, France, Greece, Ireland, Italy, Netherlands, Sweden and the UK. Panel includes 165 distinct 6-digit product categories taken from the Eurostat Harmonized Index of Consumer Prices database (HCIP). The BOOKS variable is a dummy for HCIP code CP0951. NEWS represents newspapers and magazines covering HCIP code CP0952; RECORDS is a dummy for the codes CP0914 and ELECTRO covers the codes CP0911-CP0915. BAND is a measure of country-level household broadband penetration in 2002 taken from the Eurostat Information Society database. The PMR variable is the OECD's 1-5 index of country-level product market regulation in 2003 where higher values indicator greater levels of regulation.

TABLE I.28: COUNTRY-LEVEL CHANGES IN CONSUMER PRICES, 1996-2008.

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
	$\Delta \ln RPI$	$\Delta \ln RPI$	$\Delta \ln RPI$	$\Delta \ln RPI$	$\Delta \ln RPI$	$\Delta \ln RPI$	$\Delta \ln RPI$
	UK	Germany	France	Italy	Spain	Austria	Belgium
BOOKS	0.021***	-0.005	-0.016***	-0.003	-0.005	-0.012**	0.011**
	(0.007)	(0.005)	(0.005)	(0.004)	(0.007)	(0.005)	(0.005)
RECORD	-0.149***	-0.069***	-0.112***	-0.049***	-0.095***	-0.108***	-0.130***
	(0.007)	(0.005)	(0.005)	(0.004)	(0.007)	(0.005)	(0.005)
NEWS	0.059***	0.042***	-0.003	-0.012***	-0.005	0.049***	0.021***
	(0.007)	(0.005)	(0.005)	(0.004)	(0.007)	(0.005)	(0.005)
ELECTRO	-0.387**	-0.215**	-0.325***	-0.195**	-0.290***	-0.292**	-0.223**
	(0.158)	(0.093)	(0.113)	(0.076)	(0.094)	(0.122)	(0.087)
Number of Observations	1,507	1,610	1,597	1,551	1,513	1,566	1,531

	(8)	(9)	(10)	(11)	(12)	(13)	(14)
	$\Delta \ln RPI$	$\Delta \ln RPI$	$\Delta \ln RPI$	$\Delta \ln RPI$	$\Delta \ln RPI$	$\Delta \ln RPI$	$\Delta \ln RPI$
	Netherlands	Sweden	Finland	Denmark	Ireland	Greece	All
BOOKS	-0.008	-0.021***	-0.029***	0.015**	0.001	0.003	-0.004
	(0.005)	(0.005)	(0.007)	(0.006)	(0.007)	(0.004)	(0.007)
RECORD	-0.154***	-0.041***	-0.098***	-0.049***	-0.132***	-0.170***	-0.104***
	(0.005)	(0.005)	(0.007)	(0.006)	(0.007)	(0.004)	(0.011)
NEWS	0.049***	0.024***	0.054***	0.054***	0.048***	0.064***	0.074*
	(0.005)	(0.005)	(0.007)	(0.006)	(0.007)	(0.004)	(0.039)
ELECTRO	-0.295**	-0.429***	-0.225***	-0.246***	-0.311***	-0.150***	-0.275***
	(0.129)	(0.161)	(0.080)	(0.091)	(0.056)	(0.035)	(0.031)
Number of Observations	1,545	1,548	1,577	1,577	1,582	1,568	20,272

Notes: Standard errors clustered by product category in parentheses. Countries include: Austria, Belgium, Germany, Denmark, Spain, Finland, France, Greece, Ireland, Italy, Netherlands, Sweden and the UK. Panel includes 165 distinct 6-digit product categories taken from the Eurostat Harmonized Index of Consumer Prices database (HCIP). The BOOKS variable is a dummy for HCIP code CP0951. NEWS represents newspapers and magazines covering HCIP code CP0952; RECORDS is a dummy for the codes CP0914 and ELECTRO covers the codes CP0911-CP0915. BAND is a measure of country-level household broadband penetration in 2002 taken from the Eurostat Information Society database. The PMR variable is the OECD's 1-5 index of country-level product market regulation in 2003 where higher values indicator greater levels of regulation.

TABLE I.29: ICT GOODS AND HOUSEHOLD EXPENDITURE.

Category	Code	Share
Telephone and telefax equipment (Goods)	CP0821	0.11
Telephone and telefax services (Services)	CP0831	2.60
Equipment for the reception, recording and reproduction of sound and pictures	CP0911	0.44
Photographic and cinematographic equipment and optical instruments	CP0912	0.14
Information processing equipment	CP0913	0.40
Recording media	CP0914	0.27
Repair of audio-visual, photographic and information processing equipment	CP0915	0.00
Games, toys and hobbies	CP0931	0.43
Books	CP0951	0.37
Newspapers and periodicals	CP0952	0.62
Miscellaneous printed matter	CP0953	0.09
TOTAL		5.47

Notes: Based on Eurostat Classification of Individual Consumption by Purpose (COICOP) data on household consumption. Based on 175 6-digit categories. Data is pooled across the following countries where comprehensive 6-digit data is available: Austria, Belgium, Debnmark, Finland, Greece, Ireland, Norway and Romania.

TABLE II.1: TANGIBLE VERSUS INTANGIBLE ICT CAPITAL.

	(A) Own-Account Software			*(B) Purchased Software*		*(C) Network Hardware*	
Dependent Variable	(1)	(2)	(3)	(4)	(5)	(6)	(8)
log(Sales/Labour)	ln(Y/L)	ln(Y/L)	ln(Y/L)	ln(Y/L)	ln(Y/L)	ln(Y/L)	ln(Y/L)
ln(L)	0.000	0.029**	0.000	0.000	0.029**	-0.013	0.014
log(Labour)	(0.011)	(0.011)	(0.011)	(0.011)	(0.012)	(0.011)	(0.011)
ln(K/L)	0.200***	0.200***	0.162***	0.200***	0.200***	0.199***	0.200***
log(Capital/Labour)	(0.010)	(0.010)	(0.010)	(0.010)	(0.010)	(0.010)	(0.010)
ln(ICT/L)	0.227***	0.199***	0.130***	0.227***	0.199***	0.216***	0.188***
log(ICT Capital/Labour)	(0.013)	(0.012)	(0.012)	(0.012)	(0.012)	(0.012)	(0.012)
ln(ICT Staff/L)		0.086***	0.067***		0.070**		0.065***
log(ICT Staff/Labour)		(0.013)	(0.013)		(0.028)		(0.017)
ln(W)			0.708***				
log(Average Wage)			(0.070)				
Software Index				0.002	0.020		
				(0.009)	(0.035)		
ln(ICTStaff)*Software Index					0.006		
					(0.009)		
Network-Tech						0.109***	0.208***
						(0.013)	(0.062)
ln(ICT Staff)*Network Tech							0.028*
							(0.016)
SIC4 Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Number of Observations	21,325	21,325	21,105	21,325	21,325	21,325	21,325

Notes: * significant at 10%; ** significant at 5%; *** significant at 1%. Standard errors clustered by SIC4 industry in parentheses below coefficients. Standard co include country-year effects, site-type dummies, coverage polynomials, number of establishments in company group. Countries include: Austria, Switzerland, Gerr Denmark, Spain, Finland, France, Great Britain, Italy, Netherlands, Norway, Poland, and Sweden. The variable ln(ICT Capital/Labor) represents PC-based harc capital, measured as the number of PCs per person. The variable ln(ICT Staff/Labor) measured the number of ICT-related staff (including developers) as a proport total employees. The variable Software Index is a 1-5 that measures whether 5 software technologies are present at the company-level: Enterprise Resource Pla (ERP); Databases; Industry-Specific Software; Development software; and Groupware. The Network-Tech variable is a 0-1 indicator variable that flags the preser advance networking technologies (ie: fixed and leased lines). The variable ln(W) is the log average wage across all observations for a company in AMATECH.

TABLE II.2: INNOVATION AND ICT CAPITAL , EUROPE 1999-2006.

	(1) ln(Y/L)	(2) ln(Y/L)	(3) ln(Y/L)	(4) ln(Y/L)	(5) ln(Y/L)
ln(L) log Employment	0.039* (0.020)	0.003 (0.022)	0.019 (0.022)	-0.030 (0.021)	-0.033 (0.022)
ln(K/L) Log(Capital/Employment)	0.202*** (0.021)	0.206*** (0.022)	0.201*** (0.021)	0.187*** (0.032)	0.187*** (0.032)
ln(ICT/L) Log(ICT/Employment)	0.097*** (0.030)		0.096*** (0.028)	0.247*** (0.064)	0.258*** (0.073)
Ln(PATSTOCK) log(Patent Stock)		0.044** (0.022)	0.043* (0.022)		
Above Median PATSTOCK above median				0.076** (0.036)	0.106* (0.056)
ln(ICT/L)*Above Median					0.031 (0.049)
Number of Firms	1,106	1,106	1,106	1,106	1,106
Number of Observations	1,951	1,951	1,951	1,951	1,951

Notes: * significant at 10%; ** significant at 5%; *** significant at 1%. Standard errors clustered by firm in parentheses. Sample is comprised of all firms who have ever taken out a patent with the European Patent Office (EPO). All regressions include country-year effects. Interactions between ICT capital and the linear capital and labour terms are included in column (5) but not reported. Countries include: Austria, Germany, Denmark, Spain, Finland, France, the UK, Italy, Norway and Sweden. The dependent variable ln(PATSTOCK) is the patent stock calculated using EPO data from 1979 onwards, using a 15% depreciation rate. The variable Above Median is a dummy variable for firms in the top half of the distribution of the patent stock variable.

TABLE II.3: INNOVATION EQUATIONS AND ICT SPILLOVERS, EUROPE 1998-2005.

Dependent Variable log(1+Patent Stock)	(1) ln(PATSTOCK)	(2) ln(PATSTOCK)	(3) ln(PATSTOCK)	(4) ln(PATSTOCK)	(5) ln(PATSTOCK)	(6) ln(PATSTOCK)
SPILL (ICT/Employment)$_{jkt}$	0.309***	0.233***	0.233***	0.230***	0.105**	0.025
Industry ICT Intensity	(0.076)	(0.073)	(0.073)	(0.052)	(0.049)	(0.028)
ln(R&D$_{jkt}$/Y$_{jkt}$)		0.024***	0.024***	0.019***	0.002	-0.000
Industry R&D Intensity		(0.006)	(0.006)	(0.005)	(0.002)	(0.001)
ln(Y)$_{ijkt}$				0.007	-0.000	0.014
log(Sales)				(0.014)	(0.013)	(0.011)
ln(L)$_{ijkt}$				0.184***	0.186***	0.050***
log(Employment)				(0.013)	(0.014)	(0.013)
ln(K)$_{ijkt}$				0.005	0.012	0.016*
log(Capital)				(0.009)	(0.009)	(0.009)
Number of Firms	7,728	7,728	7,728	7,728	7,728	7,728
Number of Observations	41,018	41,018	41,018	41,018	41,018	41,018

Notes: * significant at 10%; ** significant at 5%; *** significant at 1%. Standard errors clustered by country-sic4 industry in parentheses. Sample is comprised of all firms who have ever taken out a patent with the European Patent Office (EPO). All regressions include country-year effects. Countries include: Austria, Germany, Denmark, Spain, Finland, France, the UK, Italy, Norway and Sweden. The dependent variable ln(PATSTOCK) is the patent stock calculated using EPO data from 1979 onwards, using a 15% depreciation rate. The variable (ICT/Employment) is the weighted country-SIC4 average for PCs per person calculated using the Harte-Hanks CiTDB. The variable ln(R&D$_{jk}$/Y$_{jk}$) is industry R&D expenditure as a share of output and is obtained from the OECD-STAN database (ISIC2-3 digit level). Finally, the variables ln(Y), ln(L), ln(K) are firm level accounts variables for sales, employment and capital respectively.

TABLE II.4: UNCONDITIONAL COMPLEMENTARITIES IN FRENCH AUTOMOBILE RETAILING

	x_y, x_d	x_y, x_c	x_y, x_d	Π, x_y	Π, x_y	Π, x_y
All Years	0.112***	0.019	-0.036	0.789***	0.121***	0.028
Before	0.131***	0.022	-0.052	0.789***	0.138***	0.03
After	0.09	-0.007	0.005	0.785***	0.106*	0.005

Notes: Kendall’s t association coefficients. * significant at 10%; ** significant at 5%; *** significant at 1%. “All Years” refers to sample from 2000-2004. “Before” refers to observations prior to expiry of EU regulation 1475/95, “After” to observations after expiry. x_y denotes choice of scale, x_d adoption of product innovation, x_c adoption of process innovation, and Π to accounting profits. Columns refer to unconditional correlations (i.e. not controlling for other firm characteristics and unobserved heterogeneity) between pairs of endogenous variables.

TABLE II.5: ESTIMATES FOR FRENCH AUTOMOBILE RETAILING

	Model I	Model II	Model III	Model IV
θ_d Constant	-15.79	-24.75	-23.35	-51.30
	(21.40)	(22.29)	(11.04)	(12.54)
LIB	-2.83	-5.00	-3.71	-7.87
	(4.28)	(5.31)	(3.18)	(13.08)
θ_c Constant	-5.48	-6.48	-29.05	-21.86
	(11.49)	(9.38)	(7.37)	(7.03)
LIB	0.69	0.65	7.94	4.99
	(1.60)	(1.28)	(10.75)	(10.98)
θ_y Constant	-3.69	-3.92	-1.51	-2.37
	(1.13)	(1.14)	(0.49)	(0.50)
LIB	3.97	4.02	1.63	1.91
	(1.88)	(1.88)	(0.79)	(0.77)
θ_Π Constant	-2.21	-2.52	-4.88	-13.33
	(4.73)	(4.66)	(5.14)	(5.36)
LIB	2.05	2.13	-2.50	1.25
	(7.33)	(7.26)	(8.30)	(8.70)
γ	13.41	13.43	5.49	5.43
	(1.08)	(1.08)	(0.75)	(0.43)
σ_d	11.03	17.44	16.29	142.15
	(14.93)	(45.56)	(7.61)	(8.74)
σ_c	5.50	6.68	127.41	129.39
	(11.51)	(9.60)	(4.28)	(4.74)
σ_y	22.24	22.22	9.11	9.10
	(1.90)	(1.90)	(1.27)	(0.76)
σ_Π	87.22	87.23	98.22	102.60
	(2.44)	(2.44)	(2.94)	(3.15)
		(0.73)		
- ln L	1023.0	1016.4	649.0	590.4

Notes: Maximum likelihood estimates. Standard errors are reported in parentheses. * , ** and *** signify p-values less than 0.1, 0.05 and 0.01 respectively. Estimations based on a total of 639 observations. Coefficients on LIB refers to impact of expiry of EU regulation EU1475/95 on the estimated endogenous variable. Model I ignores unobserved heterogeneity and complementarities,Model II allows for unobserved heterogeneity but not complementaries, Model III allows for complementarities but not unobserved heterogeneity, Model IV is unrestricted and allows for both. $\square_{dy}$ refers to complementarities between scale and product innovation, $\square_{dc}$ to complementarities between product and process innovation, $\square_{cy}$ to complementarities between process innovation and scale.

TABLE II.6: IMPACT OF COLLABORATIVE TECHNOLOGIES IN THE PRODUCTION FUNCTION, EUROPEAN FIRMS 2000-2008.

	(1) ln(Y/L)	(2) ln(Y/L)	(3) ln(Y/L)	(4) ln(Y/L)
ln(L)	0.015	0.029**	0.029**	0.015
log(Labour)	(0.012)	(0.012)	(0.011)	(0.012)
ln(K/L)	0.199***	0.200***	0.200***	0.199***
log(Capital/Labour)	(0.010)	(0.010)	(0.010)	(0.010)
ln(ICT/L)	0.188***	0.199***	0.199***	0.188***
log(ICT Capital/Labour)	(0.012)	(0.012)	(0.012)	(0.012)
ln(ICT Staff/L)	0.085***	0.086***	0.086***	0.085***
log(ICT Staff/Labour)	(0.013)	(0.013)	(0.013)	(0.013)
NETWORK-TECH	0.108***			0.109***
	(0.013)			(0.013)
ERP-CRM		0.000		-0.004
		(0.017)		(0.018)
WORKFLOW-SOFTWARE			0.024	0.032
			(0.026)	(0.027)
SIC4 Fixed effects	Yes	Yes	Yes	Yes
Number of Observations	21,325	21,325	21,325	21,325

Notes: * significant at 10%; ** significant at 5%; *** significant at 1%. Standard errors clustered by SIC4 industry in parentheses below coefficients. Standard controls include country-year effects, site-type dummies, coverage polynomials, number of establishments in company group. Countries include: Austria, Switzerland, Germany, Denmark, Spain, Finland, France, Great Britain, Italy, Netherlands, Norway, Poland, and Sweden. The variable ln(ICT Capital/Labor) represents PC-based hardware capital, measured as the number of PCs per person. The variable ln(ICT Staff/Labor) measured the number of ICT-related staff (including developers) as a proportion of total employees. The variables ERP-CRM is a dummy variable indicating the presence of Enterprise Resource Planning (Customer Relation Management) software; WORKFLOW is an indicator for workflow software and NETWORK is a dummy for networking hardware (ie: fixed and leased lines).

TABLE II.7: DECENTRALISATION AND FIRM-LEVEL PRODUCTIVITY, EUROPEAN AND US FIRMS 2000-2006.

Dependent variable: ln(Y) log(Sales)	Basic	+ Skills	+ ICT	+Firm Fixed Effects	+Capital Interaction
	(1)	(2)	(3)	(4)	(5)
Decentralisation	0.100***	0.023*	0.046**		
Firm level decentralisation z-score	(0.015)	(0.014)	(0.021)		
ln(L)	0.594***	0.665***	0.705***	0.445***	0.438***
log(number of employees)	(0.023)	(0.021)	(0.031)	(0.076)	(0.074)
ln(K)	0.406***	0.336***	0.297***	0.373***	0.390***
ln (net tangible fixed assets)	(0.017)	(0.016)	(0.022)	(0.044)	(0.043)
ln(Skills)		0.060***	0.049**		
ln (% employees with a degree)		(0.013)	(0.019)		
ln(ICT/L)			0.126***	0.073***	0.070***
log(ICT/Employment)			(0.024)	(0.021)	(0.021)
Decentralisation*ln(ICT)			0.047***	0.032*	0.035**
Decentralisation and ICT interaction			(0.017)	(0.017)	(0.017)
Decentralisation*ln(Capital)					-0.046*
Decentralisation and Capital interaction					(0.026)
Firms	1,674	1,674	713	713	713
Observations	11,690	11,690	3,509	3,509	3,509
Country and industry controls	No	Yes	Yes	Yes	Yes
Other controls	No	Yes	Yes	Yes	Yes
Firm fixed effects	No	No	No	Yes	Yes

Notes: * significant at 10%; ** significant at 5%; *** significant at 1%. Estimation by OLS with robust standard errors in parentheses. The sample includes firms based in France, Germany, Italy, Portugal, Poland, Sweden, the UK and the US. The dependent variable is log (sales). DECENTRALISATION z-score index, measured by the degree of plant manager's autonomy over hiring, investment, products and pricing. Standard errors are clustered at the firm level. "Country and industry" controls include a full set of country and three digit industry dummies. OTHER CONTROLS includes a full set of noise controls (the day of the week the interview took place, an interview reliability score, the manager's seniority and tenure, the duration of the interview, and 4 dummies for missing values in seniority, tenure, duration and reliability) and controls for accounts consolidation status and public listing.

TABLE II.8 - PLANT MANAGER AUTONOMY, EUROPEAN AND US FIRMS 2000-2006.

	(1)	(2)	(3)	(4)	(5)	(6)
Dependent Variable	Plant Manager Autonomy					
ERP	0.097*	0.104*			0.114**	0.116**
	(0.053)	(0.054)			(0.053)	(0.054)
NETWORK			-0.107**	-0.098*	-0.123**	-0.110**
			(0.053)	(0.052)	(0.053)	(0.053)
ln(Percentage College)		0.100***		0.097***		0.098***
		(0.032)		(0.032)		(0.032)
ln(PC/Employee)		-0.041		-0.020		-0.031
		(0.031)		(0.031)		(0.031)
ln(Firm Employment)	0.070*	0.063	0.073*	0.068*	0.073*	0.067*
	(0.040)	(0.040)	(0.040)	(0.040)	(0.040)	(0.040)
Plant Employment	0.151***	0.148***	0.151***	0.151***	0.149***	0.147***
	(0.044)	(0.045)	(0.044)	(0.045)	(0.044)	(0.045)
Foreign Multinational	0.177**	0.178**	0.202**	0.196**	0.193**	0.190**
	(0.080)	(0.080)	(0.079)	(0.079)	(0.080)	(0.080)
Domestic Multinational	0.195**	0.184**	0.208**	0.193**	0.203**	0.190**
	(0.082)	(0.083)	(0.082)	(0.083)	(0.082)	(0.083)
Number of Firms	948	948	948	948	948	948

Notes: * = significant at the 10% level, **= significant at the 5% level, ***=significant at the 1% level. The dependent variable is the z-score of plant manager autonomy (mean=0 and standard deviation=1) across four questions relating to plant manager's control over hiring, investment, product introduction and marketing (see text). All columns are estimated by OLS with standard errors in parentheses (robust and clustered by firm). The sample includes firms based in France, Germany, Italy, Portugal, Poland, Sweden, the UK and the US (country dummies included). All columns include a full set of three digit industry dummies and "Noise controls" (analyst fixed effects, plant manager seniority and tenure in company, the day of the week the interview was conducted, interview duration and reliability). "ERP" denotes Enterprise Resource Planning and "NETWORK" denotes the firm has an internal network (leased lines or frame relays). All columns exclude firms where the plant manager is the CEO and include a dummy equal to unity if the CEO is on site.

TABLE II.9 – WORKERS' AUTONOMY, EUROPEAN AND US FIRMS 2000-2006.

	(1)	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**
Dependent Variable				**Workers' Autonomy**		
CAD/CAM	0.582**	0.540**			0.586**	0.535*
	(0.271)	(0.275)			(0.268)	(0.274)
	[0.073]	[0.055]			[0.072]	[0.053]
NETWORK			-0.214	-0.229	-0.218	-0.226
			(0.171)	(0.178)	(0.172)	(0.180)
			[-0.027]	[-0.023]	[-0.027]	[-0.023]
Ln(Percentage College)		0.467***		0.471***		0.468***
		(0.111)		(0.110)		(0.110)
		[0.047]		[0.048]		[0.047]
Ln(PC/Employee)		-0.026		0.003		-0.013
		(0.099)		(0.099)		(0.100)
		[-0.003]		[0]		[-0.001]
Ln(Firm Employment)	-0.036	-0.039	-0.028	-0.027	-0.032	-0.033
	(0.104)	(0.103)	(0.104)	(0.102)	(0.103)	(0.102)
	[-0.005]	[-0.004]	[-0.003]	[-0.003]	[-0.004]	[-0.003]
Plant Employment	-0.113	-0.129	-0.116	-0.124	-0.117	-0.128
	(0.128)	(0.132)	(0.128)	(0.131)	(0.128)	(0.132)
	[-0.014]	[-0.013]	[-0.014]	[-0.013]	[-0.014]	[-0.013]
Foreign Multinational	0.385*	0.336	0.432*	0.384	0.417*	0.368
	(0.232)	(0.247)	(0.233)	(0.249)	(0.234)	(0.250)
	[0.055]	[0.039]	[0.062]	[0.045]	[0.059]	[0.042]
Domestic Multinational	0.336	0.247	0.372*	0.293	0.368	0.283
	(0.226)	(0.231)	(0.226)	(0.233)	(0.226)	(0.233)
	[0.046]	[0.027]	[0.052]	[0.033]	[0.05]	[0.031]
Number of firms	687	687	687	687	687	687

Notes: * = significant at the 10% level, **= significant at the 5% level, ***=significant at the 1% level. The dependent variable in all columns is a dummy equal to unity if the plant manager reports that tasks allocation and pace of work are determined mostly by workers (instead of managers). All columns are estimated by probit ML with standard errors in parentheses (robust and clustered by firm). Marginal effects (evaluated at the mean) reported in square brackets. All columns exclude firms where the plant manager is the CEO and include a dummy equal to unity if the CEO is on site. Number of countries and definition of controls follow notes of Table 30.

TABLE II.10 - PLANT MANAGER SPAN OF CONTROL, EUROPEAN AND US FIRMS 2000-2006.

	(1)	(2)	(3)	(4)	(5)	(6)
Dependent Variable	Plant Manager Span of Control					
CAD/CAM	0.167**	0.153**			0.168**	0.155**
	(0.072)	(0.076)			(0.072)	(0.076)
NETWORK			0.054	0.051	0.054	0.053
			(0.043)	(0.043)	(0.043)	(0.043)
Ln(Percentage College)		0.059**		0.061***		0.059**
		(0.023)		(0.023)		(0.023)
ln(PC/Employee)		0.010		0.008		0.006
		(0.024)		(0.024)		(0.024)
ln(Firm Employment)	0.041	0.041	0.042	0.041	0.038	0.038
	(0.027)	(0.026)	(0.027)	(0.026)	(0.027)	(0.026)
Plant Employment	0.024	0.032	0.028	0.035	0.025	0.031
	(0.031)	(0.032)	(0.032)	(0.032)	(0.032)	(0.032)
Foreign Multinational	0.059	0.037	0.054	0.032	0.052	0.031
	(0.058)	(0.056)	(0.058)	(0.056)	(0.058)	(0.056)
Domestic Multinational	0.129**	0.105*	0.124**	0.100*	0.125**	0.102*
	(0.060)	(0.057)	(0.060)	(0.057)	(0.059)	(0.057)
Number of firms	859	859	859	859	859	859

Notes: * = significant at the 10% level, **= significant at the 5% level, ***=significant at the 1% level. The dependent variable in all columns is the log of the number of employees reporting directly to the plant manager. All columns are estimated by OLS with standard errors in parentheses (robust and clustered by firm). All columns exclude firms where the plant manager is the CEO and include a dummy equal to unity if the CEO is on site. The sample includes firms based in France, Germany, Italy, Portugal, Poland, Sweden, the UK and the US (country dummies included). All columns include a full set of three digit industry dummies and “Noise controls” (analyst fixed effects, plant manager seniority and tenure in company, the day of the week the interview was conducted, interview duration and reliability). “CAD/CAM” denotes Computer Assisted Design or Manufacturing software and “NETWORK” denotes the firm has an internal network (leased lines or frame relays).

TABLE II.11 – PLANT MANAGER AUTONOMY (USING EFFECTIVE NETWORK PRICES AS EXOGENOUS SHIFTER OF NETWORK USAGE), EUROPEAN AND US FIRMS 2000-2006.

	(1)	(2)	(3)
Dependent Variable		Plant Manager Autonomy	
Regression	Basic	Reduced Form	Reduced Form
Firm-level NETWORK	-0.132*		
	(0.068)		
(Industry-level NETWORK %) *ln(NETWORK Price)		4.791**	5.802**
		(2.189)	(2.766)
(Industry-level NETWORK %)* ln(Average Years of Schooling)			1.443
			(5.024)
(Industry-level NETWORK %)*ln(GDP Per Capita)			1.541
			(2.546)
Number of Firms	1,020	1,020	1,020

Notes: * = significant at the 10% level, **= significant at the 5% level, ***=significant at the 1% level. The dependent variable is the z-score of plant manager autonomy. Standard errors are robust and clustered at the country by three digit industry pair in all columns. All columns exclude firms where the plant manager is the CEO and include a dummy equal to unity if the CEO is on site. The sample includes firms based in France, Germany, Italy, Portugal, Poland, Sweden, the UK and the US (country dummies included). All columns include noise controls, firm controls and industry dummies as in previous tables. “Firm-level NETWORK” represents access to an internal network (leased lines or frame relays). “Industry-level NETWORK” represents the fraction of workers with access to an internal network (leased lines or frame relays) in the three digit industry across all countries (see text). “NETWORK Price” is the cost of an annual subscription to a leased line contract at 2006 PPP USD (taken from the OECD *Telecommunication Handbook*, 2007). The variables “Average Years of Schooling” and “GDP Per Capita PPP” are taken from the World Development Indicators (2006).

TABLE II.12: ICT USAGE AND WORK-LIFE BALANCE (WLB), RESULTS FROM GERMAN WLB SURVEY

	(1)	(2)	(3)	(4)	(5)
Dependent Variable			Perceived WLB		
Method			OLS		
ICT_AFTER	-0.056*	-0.026	-0.263**		
	(0.031)	(0.033)	(0.131)		
ICT_PRIVATE				0.452*	0.516**
				(0.256)	(0.254)
ICT_PRIVATE_SQUARE				-0.080**	-0.088**
				(0.040)	(0.039)
Working Hours		-0.018***	-0.019***		-0.018***
		(0.006)	(0.007)		(0.006)
Flextime (dummy)			-0.746		
			(0.527)		
ICT_AFTER·Flextime Interaction			0.238*		
			(0.137)		
Interview controls (Interviewer dummies, interviewee willingness, interviewee patience)	YES	YES	YES	YES	YES
Personal demographics (Interviewee age, interviewee tenure(log), interviewee sex, interviewee children)		YES	YES		YES
Observations	254	254	236	254	254
R-squared	0.079	0.123	0.149	0.091	0.145

Notes: Standard errors in parentheses, *** p<0.01, ** p<0.05, * p<0.1. Interview controls are always included as general interview atmosphere may influence the interviewee's willingness to respond openly to potentially contentious questions.

TABLE II.13: FLEXIBLE ICT, FAMILY-FRIENDLY WORK PRACTICES AND PROFITS,RESULTS FROM GERMAN WLB SURVEY

	(1)	(2)	(3)	(4)
Dependent Variable	ROA	ROS	ROA	ROS
Method	OLS			
FFWP	9.90**	8.74**	14.47***	11.87***
	(4.95)	(4.10)	(5.20)	(4.38)
FLEX_ICT	0.89	0.50	7.65	4.84
	(8.18)	(6.49)	(8.48)	(6.80)
FFWP·FLEX_ICT			140.41**	92.84*
			(59.98)	(49.59)
No. of employees (log)	-0.43	0.42	-0.45	0.45
	(0.89)	(0.72)	(0.87)	(0.71)
Industry dummies (1-digit SIC codes)	YES	YES	YES	YES
Observations	94	90	94	90
R-squared	0.090	0.097	0.145	0.135

Notes: Standard errors in parentheses, *** p<0.01, ** p<0.05, * p<0.1. ROA is return on assets, ROS is return on sales. Models (3) and (4) include an interaction term between family-friendly workplace practices and the use of flexible ICT.

TABLE III.1: TOP 100 MULTINATIONALS AND SUBSIDIARY ACTIVITIES - USA, EUROPE, AND JAPAN

Country/Region (Ultimate Owner)	(1) US MNE	(2) European MNE	(3) Japanese MNE
% Manufacturing	0.229	0.267	0.176
Number of SIC2	43.33	34.80	39.35
Number of SIC4	172.73	150.15	174.64
Number of Subsidiaries	255.5	158.4	210.6
Mean Employment (Subsidiary)	1711	11504	3751
Mean Turnover (Subsidiary)	950.5	3898.2	1998.9
% Subsidiaries in China	0.029	0.016	0.015
% Subsidiaries in Western Europe	0.080	0.231	0.497
% Subsidiaries in Scandinavia	0.005	0.026	0.030
% Subsidiaries in USA	0.042	0.315	0.074
% Subsidiaries in Eastern Europe	0.032	0.053	0.124
% Low-Tech SIC4 Activities	0.183	0.106	0.123
Number of Ultimate Owners	20	37	43

Notes: Sample is based on the Top 100 ultimate owners in the ORBIS database (by turnover) in the US, Europe and Japan. The total number of subsidiaries in 20,025. The number of SIC2 and SIC4 activities is a count of distinct industry activities per ultimate owner. The %Subsidiaries statistics report the unweighted proportion of subsidiaries located in a particular country or region. The variable Low-Tech is a dummy variable that equals one if the sic4 activity falls into the lowest two quintiles of the ICT-based industry technology ladder. The technology ladder is an index of PCs per person constructed from the full sample of European and US Harte-Hanks data pooled from 1999 onwards.

TABLE III.2: TOP 100 MULTINATIONALS – LOCATION OF LOW TECH INDUSTRY ACTIVITIES

	MANUFACTURING			
Dependent Variable	(1)	(2)	(3)	(4)
Prob(Low-tech Industry)	Pr(Low-Tech)	Pr(Low-Tech)	Pr(Low-Tech)	Pr(Low-Tech)
Subsidiary - China	0.116**	0.118***	0.118***	0.111***
	(0.045)	(0.045)	(0.036)	(0.035)
Subsidiary - Western Europe	-0.023	-0.019	-0.015	-0.012
	(0.019)	(0.019)	(0.015)	(0.014)
Subsidiary - Scandinavia	0.018	0.016	0.021	0.002
	(0.050)	(0.050)	(0.039)	(0.037)
Subsidiary - Eastern Europe	-0.001	-0.000	0.045	0.046
	(0.035)	(0.035)	(0.029)	(0.031)
Subsidiary – USA	0.040*	0.048**	0.025	0.015
	(0.023)	(0.023)	(0.022)	(0.021)
Home Country	-0.058***	-0.060***	-0.002	-0.005
	(0.016)	(0.016)	(0.015)	(0.015)
Ultimate Owner - USA	-0.026	-0.008	-0.079***	
	(0.020)	(0.028)	(0.026)	
Ultimate Owner - Japan	0.104***	0.117***	0.042*	
	(0.020)	(0.022)	(0.023)	
ln(Employment)		0.023	-0.178***	
log(Global Employment)		(0.036)	(0.032)	
ln(Turnover)		-0.037	0.212***	
log(Global Turnover)		(0.038)	(0.033)	
Ultimate Owner SIC2	No	No	Yes	Na
Ultimate Owner fixed effects	No	No	No	Yes
Number of Observations	7,978	7,978	7,978	7,978

Notes: * significant at 10%; ** significant at 5%; *** significant at 1% Standard errors clustered by subsidiary firm in parentheses. The lowest unit of observation in this cross-section is subsidiary-sic4 where subsidiaries can have multiple sic4 industries. The dependent variable Pr(Low-Tech) is a dummy variable that equals one if the sic4 activity falls into the lowest two quintiles of the ICT-based industry technology ladder. Log employment and turnover defined as the total across subsidiaries per ultimate owner.

TABLE III.3 – UK DESCRIPTIVE STATISTICS BROKEN DOWN BY MULTINATIONAL STATUS, (Normalised to 100 for the 3-digit SIC and year average).

		Employment	Value added per Employee	Gross output per Employee	Non ICT Capital per Employee	Materials per Employee	ICT Capital per Employee
US Multinationals							
	Mean	162.26	127.96	123.63	129.61	123.81	152.13
	St. Deviation	297.58	163.17	104.81	133.91	123.35	234.41
	Observations	569	569	569	569	569	569
Other Multinationals							
	Mean	148.58	113.71	115.22	120.65	116.02	119.58
	St. Deviation	246.35	107.87	86.50	126.83	107.63	180.34
	Observations	2,119	2,119	2,119	2,119	2,119	2,119
UK domestic							
	Mean	68.78	89.86	89.69	86.33	89.29	83.95
	St. Deviation	137.72	104.50	102.09	127.16	129.37	188.30
	Observations	4,433	4,433	4,433	4,433	4,433	4,433

Notes: These are 2001 values from our sample of 7,121 establishments.

TABLE III.4 – ESTIMATES OF THE UK PRODUCTION FUNCTION ALLOWING THE ICT. COEFFICIENT TO DIFFER BY OWNERSHIP STATUS

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Dependent variable: ln(Output/L)	**ln(Q/L)**	**ln(Q/L)**	**ln(Q/L)**	**ln(Q/L)**	**ln(Q/L)**	**ln(Q/L)**	**ln(Q/L)**	**ln(Q/L)**
Sectors	All Sectors	All Sectors	All Sectors	ICT Using Intensive Sectors	Other Sectors	All Sectors	ICT Using Intensive Sectors	Other Sectors
USA*ln(C/L)	-	-	0.0202***	0.0380***	0.0120	0.0093	0.0368**	-0.0060
USA ownership*ICT capital per employee			(0.0072)	(0.0128)	(0.0084)	(0.0085)	(0.0144)	(0.0098)
MNE*ln(C/L)	-	-	0.0036	-0.0011	0.0062	0.0010	-0.0003	0.0008
Non-US multinational *ICT capital per employee			(0.0045)	(0.0062)	(0.0060)	(0.0042)	(0.0064)	(0.0053)
ln(C/L)	-	0.0457***	0.0428***	0.0373***	0.0457***	0.0152***	0.0123**	0.0157***
ICT capital per employee		(0.0024)	(0.0029)	(0.0038)	(0.0039)	(0.0030)	(0.0051)	(0.0036)
ln(M/L)	0.5575***	0.5474***	0.5477***	0.6216***	0.5067***	0.4031***	0.5018***	0.3606***
Materials per employee	(0.0084)	(0.0083)	(0.0083)	(0.0142)	(0.0104)	(0.0178)	(0.0279)	(0.0210)
ln(K/L)	0.1388***	0.1268***	0.1268***	0.1106***	0.1459***	0.0900***	0.1056***	0.0666***
Non-ICT Capital per employee	(0.0071)	(0.0068)	(0.0068)	(0.0093)	(0.0092)	(0.0159)	(0.0228)	(0.0209)
ln(L)	-0.0052*	-0.0112***	-0.0111***	-0.0094**	-0.0121***	-0.1986***	-0.1279***	-0.2466***
Labor	(0.0027)	(0.0027)	(0.0027)	(0.0037)	(0.0036)	(0.0217)	(0.0319)	(0.0279)
USA	0.0711***	0.0641***	0.0733***	0.0440**	0.0892***	0.0214	0.0451	-0.0070
USA Ownership	(0.0140)	(0.0135)	(0.0144)	(0.0213)	(0.0189)	(0.0224)	(0.0366)	(0.0242)
MNE	0.0392***	0.0339***	0.0372***	0.0149	0.0441***	0.0081	0.0173	-0.0008
Non-US multinational	(0.0079)	(0.0078)	(0.0093)	(0.0134)	(0.0124)	(0.0103)	(0.0172)	(0.0126)
Fixed effects	**NO**	**NO**	**NO**	**NO**	**NO**	**YES**	**YES**	**YES**
Observations	21,746	21,746	21,746	7,784	13,962	21,746	7,784	13,962
Test USA*ln(C/L)=MNE*ln(C/L), p-value		-	0.0320	0.0035	0.5272	0.3622	0.0094	0.5210
Test USA=MNE, p-value	0.0206	0.0232	0.0113	0.1755	0.0151	0.5545	0.4301	0.8145

Notes: * significant at 10%; ** significant at 5%; *** significant at 1%. The dependent variable in all columns is the log of gross output per employee. The time period is 1995-2003. The estimation method in all columns is OLS. Columns (6) to (8) include establishment level fixed effects. Standard errors in brackets under coefficients in all columns are clustered by establishment (i.e. robust to heteroskedasticity and autocorrelation of unknown form). All columns include a full set of three digit industry dummies interacted with a full set of time dummies and as additional controls: dummies for establishment age (interacted with a manufacturing dummy), region, multi-establishment group (interacted with ownership type) and ICT survey. See Appendix Table A1 for definition of ICT using intensive sectors. “Test USA*ln(C/L)=MNE*ln(C/L)” is test of whether the coefficient on USA*ln(C/L) is significantly different from the coefficient on MNE*ln(C/L), etc.

TABLE III.5 – UK PRODUCTION FUNCTIONS BEFORE AND AFTER TAKEOVERS

	(1)	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**
Sample	Before Takeover	Before Takeover	After Takeover	After Takeover	After Takeover	After Takeover (drop UK domestic acquirers)
Dependent Variable: ln(Output per employee)	ln(Q/L)	ln(Q/L)	ln(Q/L)	ln(Q/L)	ln(Q/L)	ln(Q/L)
USA*ln(C/L)		-0.0672		0.0541**		
USA Takeover*ICT capital per employee		(0.0749)		(0.0273)		
MNE*ln(C/L)		-0.0432		0.0073		
Non-US multinational Takeover*ICT capital per employee		(0.0463)		(0.0150)		
USA	-0.0661	-0.1055	0.0353	0.0619		
USA Takeover	(0.0663)	(0.0863)	(0.0402)	(0.0461)		
MNE	0.0321	-0.0009	0.0117	0.0205		
Non-US multinational Takeover	(0.0565)	(0.0710)	(0.0298)	(0.0342)		
USA*ln(C/L) one year after takeover					0.0192	0.0191
					(0.0378)	(0.0562)
USA*ln(C/L) two and three years after takeover					0.0661**	0.1303**
					(0.0294)	(0.0573)
MNE*ln(C/L) one year after takeover					-0.0091	
					(0.0197)	
MNE*ln(C/L) two and three years after takeover					0.0115	
					(0.0162)	
USA one year after takeover					0.0019	0.0014
					(0.0542)	(0.0716)
USA two and three years after takeover					0.0934*	0.0942
					(0.0485)	(0.0856)
MNE one year after takeover					-0.0178	
					(0.0411)	
MNE two and three years after takeover					0.0327	
					(0.0361)	
ln(C/L)	0.0744**	0.0935**	0.0395***	0.0287***	0.0288***	0.0282
ICT capital per employee	(0.0299)	(0.0432)	(0.0079)	(0.0088)	(0.0088)	(0.0224)
ln(M/L)	0.5486***	0.5487***	0.6871***	0.6892***	0.6886***	0.7323***
Materials per employee	(0.0489)	(0.0481)	(0.0173)	(0.0173)	(0.0172)	(0.0292)
ln(K/L)	0.1759***	0.1718***	0.0350**	0.0350**	0.0353**	-0.0108
Non-ICT Capital per employee	(0.0343)	(0.0335)	(0.0160)	(0.0159)	(0.0159)	(0.0431)
ln(L)	-0.0185	-0.0215	-0.0117	-0.0111	-0.0112	-0.0358*
Labor	(0.0292)	(0.0276)	(0.0108)	(0.0108)	(0.0107)	(0.0213)
Observations	261	261	1,006	1,006	1,006	241
Test USA*ln(C/L) = MNE*ln(C/L), p-value		0.7037		0.0965		

Test USA = MNE, p-value	0.1637	0.1773	0.5979	0.4056	
Test (USA one year)*ln(C/L) = (MNE one year)*ln(C/L), p-value					0.4948
Test (USA two plus years)*ln(C/L) = (MNE two plus years)*ln(C/L), p-value					0.0734
Test USA one year = MNE one year, p-value					0.7463
Test USA two plus years = MNE two plus years, p-value					0.2481

Notes: * significant at 10%; ** significant at 5%; *** significant at 1%. The sample is of all establishments in the ICT intensive sectors who were taken over at some point (the omitted base is “domestic takeovers” – a UK firms taking other another firms). We drop takeovers that do not result in a change of ownership category (e.g. US takeovers of US firms, non-US MNE takeovers of non-US MNEs and domestic takeovers of domestic firms). The dependent variable in all columns is the log of gross output per employee. The time period is 1995-2003. The estimation method is OLS. Standard errors in brackets under coefficients are clustered by establishment. A takeover is defined as a change in the establishment foreign ownership marker or - for UK domestic establishment - as a change in the enterprise group marker. The "before" period is defined as the interval between one and three years before the takeover takes place. The "after" period is defined as the interval between one and three years after the takeover takes place. The year in which the takeover takes place is excluded from the sample. All columns include a full set of two digit industry dummies interacted with time dummies and as additional controls: age, region dummies, a multi-establishment group dummy and an ICT survey dummy. “Test USA*ln(C/L) =MNE*ln(C/L)” is test of whether the coefficient on USA*ln(C/L) is significantly different from the coefficient on MNE*ln(C/L), etc.

TABLE III.6
EUROPEAN FIRM-LEVEL PANEL DATA WITH DIRECT MEASURES OF MANAGEMENT

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Dependent Variable	ln(Q/L)	ln(Q/L)	ln(Q/L)	ln(Q/L)	ln(Q/L)	ln(Q/L)	ln(C/L)	ln(C/L)
Fixed Effects	NO	NO	NO	NO	YES	YES	NO	NO
USA*ln(C/L) USA ownership*Computers per employee		0.1790** (0.0733)		0.0784 (0.0720)	0.0518 (0.0713)	0.0192 (0.0785)		
MNE*ln(C/L) Non-US multinational*Computers per employee		-0.0263 (0.0586)		-0.0235 (0.0553)	0.0218 (0.0547)	0.0235 (0.0550)		
People Management People management			0.0188 (0.0153)	0.0189 (0.0152)				0.0882*** (0.0246)
People Management*ln(C/L) People management*Computers per employee			0.1451*** (0.0331)	0.1404*** (0.0344)	0.1284* (0.0773)	0.0994* (0.0581)		
ln (K/L) Non-ICT Capital per employee	0.2355*** (0.0180)	0.1838*** (0.0284)	0.1782*** (0.0276)	0.1791*** (0.0276)	0.2347** (0.0926)	0.2316*** (0.0882)		
ln(L) Labor	-0.0257 (0.0182)	0.0421 (0.0360)	0.0421 (0.0344)	0.0409 (0.0349)	-0.2182 (0.2600)	-0.2347 (0.2497)		
ln(C/L) Computers per employee		0.1256*** (0.031)	0.1430*** (0.0284)	0.1463*** (0.0303)	-0.0493 (0.0596)	-0.2282 (0.1738)		
USA USA Ownership	0.2699*** (0.0476)	0.0779 (0.0481)	0.1111** (0.0446)	0.0837* (0.046)			0.2601*** (0.0742)	0.2150*** (0.0732)
MNE Non-US multinational	0.1927*** (0.0340)	0.1597*** (0.0363)	0.1604*** (0.0355)	0.1618*** (0.0357)			0.0492 (0.0596)	0.0367 (0.0591)
ln(Degree) Percentage employees with a college degree		0.0433** (0.0183)	0.0375** (0.0184)	0.0370** (0.0184)			0.0585** (0.0293)	0.0359 (0.0296)
ln(Degree)*ln(C/L) Percentage employees with a college degree*Computers per employee						0.0700 (0.0484)		
Observations	7,420	2,555	2,555	2,555	2,555	2,555	2,555	2,555

Test USA=MNE, p-value	0.1410	0.1206	0.3094	0.1264				
Test USA*ln(C/L)= MNE*ln(C/L), p-value		0.0189		0.2419	0.6360	0.9565	0.0095	0.0253

Notes: * significant at 10%; ** significant at 5%; *** significant at 1%. The dependent variable in all columns (1) to (6) is the log of sales per employee, and in columns (7) and (8) is the log of computers per employee. The time period is 1999-2006, containing data from France, Germany, Italy, Poland, Portugal, Sweden and the UK. The estimation method in all columns is OLS. Columns (5) to (7) include firm level fixed effects. Standard errors in brackets under coefficients in all columns are clustered by firm (i.e. robust to heteroskedasticity and autocorrelation of unknown form). All columns include a full set of three digit industry dummies, country dummies interacted with a full set of time dummies and a public listing indicator. Columns (2) to (9) are weighted by the survey coverage rate in the Harte-Hanks data, plus include a 5th order Taylor expansion for the coverage ratio to control for any potential survey bias. "Test USA*ln(C/L)=MNE*ln(C/L)" is test of whether the coefficient on USA*ln(C/L) is significantly different from the coefficient on MNE*ln(C/L), etc. 719 firms in all columns except column (1) where there are 1,633 firms.

TABLE III.7: MULTINATIONAL AND THE ICT-INTENSIVE SECTOR: RESULTS FOR UK ESTABLISHMENTS, 1995-2003.

	(1)	(2)	(3)	(4)
Dependent Variable: ln(Y/L)	ln(Y/L)	ln(Y/L)	ln(Y/L)	ln(Y/L)
Sectors	All Sectors	ICT Using Intensive Sectors	ICT Using Intensive Sectors	Other Sectors
USA*ln(C/L)	0.0202***	0.0380***	0.0368**	-0.0060
USA ownership*ICT capital per employee	(0.0072)	(0.0128)	(0.0144)	(0.0098)
MNE*ln(C/L)	0.0036	-0.0011	-0.0003	0.0008
Non-US multinational *IT capital per employee	(0.0045)	(0.0062)	(0.0064)	(0.0053)
ln(C/L)	0.0428***	0.0373***	0.0123**	0.0157***
IT capital per employee	(0.0029)	(0.0038)	(0.0051)	(0.0036)
ln(M/L)	0.5477***	0.6216***	0.5018***	0.3606***
Materials per employee	(0.0083)	(0.0142)	(0.0279)	(0.0210)
ln(K/L)	0.1268***	0.1106***	0.1056***	0.0666***
Non-ICT Capital per employee	(0.0068)	(0.0093)	(0.0228)	(0.0209)
ln(L)	-0.0111***	-0.0094**	-0.1279***	-0.2466***
Labor	(0.0027)	(0.0037)	(0.0319)	(0.0279)
USA	0.0733***	0.0440**	0.0451	-0.0070
USA Ownership	(0.0144)	(0.0213)	(0.0366)	(0.0242)
MNE	0.0372***	0.0149	0.0173	-0.0008
Non-US multinational	(0.0093)	(0.0134)	(0.0172)	(0.0126)
Firm Fixed effects	NO	NO	YES	YES
Observations	21,746	7,784	7,784	13,962
Test USA*ln(C/L)=MNE*ln(C/L), p-value	0.0320	0.0035	0.0094	0.5210
Test USA=MNE, p-value	0.0113	0.1755	0.4301	0.8145

Notes: * significant at 10%; ** significant at 5%; *** significant at 1%. The dependent variable in all columns is the log of gross output per employee. The time period is 1995-2003. The estimation method in all columns is OLS. Standard errors in brackets under coefficients in all columns are clustered by establishment (i.e. robust to heteroskedasticity and autocorrelation of unknown form). All columns include a full set of three digit industry dummies interacted with a full set of time dummies as per Table III.4

TABLE III.8: ICT ADOPTION AND IMPORT COMPETITION, 5 YEAR DIFFERENCES

Dependent Variable: PCs per worker	$\Delta \ln(ICT / L)$			
Change in log(PCs per worker)	**(1)**	**(2)**	**(3)**	**(4)**
$\Delta\left(M_{jk}^{China} / M_{jk}^{World}\right)$ Change in Chinese Imports	0.429*** (0.080)	0.396*** (0.077)	0.361*** (0.076)	0.195*** (0.068)
$\Delta \ln L$ Change in employment				-0.617*** (0.010)
Country Year Effects	No	Yes	Yes	Yes
Site-Type Controls	No	No	Yes	Yes
Number of Firms	22,957	22,957	22,957	22,957
Observations	37,500	37,500	37,500	37,500

Notes: *** denotes 1% significance; ** denotes 5% significance; * denotes 10% significance. Sample period is 2007-2000 (so first 5-year difference is 2005-2000). Estimation is by OLS with standard errors clustered by country (k) by four digit industry (j) pair in parentheses. There are 2,816 distinct country by industry pairs. All changes are in five-year differences, e.g. $\Delta\left(M_{jk}^{China} / M_{jk}^{World}\right)$ represents the 5-year difference in Chinese imports as a fraction of total imports in a four-digit industry by country pair. Countries include Austria, Denmark, Finland, France, Germany, Italy, Norway, Spain, Sweden, Switzerland and the UK. Site type controls are dummies for establishment type; these are Divisional HQ, Divisional Branch, Enterprise HQ or a Standalone Branch. “Number of Firms” here is defined as the number of establishments for all columns.

TABLE III.9: IMPORT COMPETITION, EMPLOYMENT AND ICT, EUROPEAN ESTABLISHMENTS 2000-2007.

	5-year change in log employment			
	(1)	(2)	(3)	(4)
Dependent Variable	$\Delta \ln N$	$\Delta \ln N$	$\Delta \ln N$	$\Delta \ln N$
$\Delta\left(M_{jk}^{China} / M_{jk}^{World}\right)$	-0.277***	-0.203***	-0.379***	-0.396***
Change in Chinese Imports	(0.074)	(0.072)	(0.105)	(0.120)
$\Delta\left(M_{jk}^{China} / M_{jk}^{World}\right)$ * (ICT/ N) $_{t-5}$			0.385**	
Change Chinese Imports*PCs per worker at (t-5)			(0.157)	
(ICT/ N) $_{t-5}$		0.241***	0.230***	
PCs per worker (t-5)		(0.009)	(0.010)	
Quintile2* $\Delta\left(M_{jk}^{China} / M_{jk}^{World}\right)$				0.165
				(0.126)
Quintile3* $\Delta\left(M_{jk}^{China} / M_{jk}^{World}\right)$				0.009
				(0.174)
Quintile4* $\Delta\left(M_{jk}^{China} / M_{jk}^{World}\right)$				0.362***
				(0.139)
Highest Quintile 5 of (ICT/ N)$_{t-5}$* $\Delta\left(M_{jk}^{China} / M_{jk}^{World}\right)$				0.514***
				(0.159)
$\left(M_{jk}^{China} / M_{jk}^{World}\right)_{t-4}$				
Level Chinese Imports at (t-4)				
$\ln(PATSTOCK)$				
Log of patent stock				
$\ln(PATSTOCK)^{*}\left(M_{jk}^{China} / M_{jk}^{World}\right)_{t-4}$				
Log of patent stock*level of Chinese imports at (t-4)				
Country Year Effects	Yes	Yes	Yes	Yes
Site-Type Controls	Yes	Yes	Yes	Yes
Number of Firms	22,957	22,957	22,957	22,957
Observations	37,500	37,500	37,500	37,500

Notes: *** denotes 1% significance; ** denotes 5% significance; * denotes 10% significance. Estimation by OLS with standard errors (clustered by country by four digit industry pair) in parentheses. Columns (1)-(4) estimated as long differences (DIFFS), column (5) estimated as within groups (WG). $\Delta\left(M_{jk}^{China} / M_{jk}^{World}\right)$ represents the 5-year difference in Chinese imports as a fraction of total imports in a four-digit industry by country pair. There are 2,816 distinct country by industry pairs for columns (1)-(4) and 2,225 for column (5). Countries include Austria, Denmark, Finland, France, Germany, Italy, Norway, Spain, Sweden, Switzerland and the UK. Site type controls include dummies Divisional HQ, a Divisional Branch, Enterprise HQ or a Standalone Branch. Quintiles represent bands of establishments ordered from highest (5) to the lowest (1) in terms of their baseline PC intensity, (ICT/ N) $_{t-5}$. Note that linear quintile terms are included in column (4) but not reported in the table. Sample period is 2000 to 2007 for columns (1)-(4) and 1996-2005 for column (5). "Number of Firms" is defined as number of establishments for Panel(A) and the number of companies for panel (B).

TABLE III.10: EXIT EQUATIONS, EUROPEAN ESTABLISHMENTS, 2000-2007.

Dependent Variable	Pr(Exit)			
	(1)	(2)	(3)	(4)
$\Delta\left(M_{jk}^{China}/M_{jk}^{World}\right)$ Change in Chinese Imports	0.118** (0.047)	0.182** (0.072)	0.274*** (0.098)	-0.060 (0.049)
$\Delta\left(M_{jk}^{China}/M_{jk}^{World}\right)$ * (ICT/ N) $_{t-5}$ Change Chinese Imports*PCs per worker at (t-5)		0.137 (0.112)		
$\Delta\left(M_{jk}^{China}/M_{jk}^{World}\right)$ * Quintile1 Change Chinese Imports*Lowest PC Quintile (t-5)				-0.214** (0.102)
Quintile2* $\Delta\left(M_{jk}^{China}/M_{jk}^{World}\right)$			0.238** (0.104)	
Quintile3* $\Delta\left(M_{jk}^{China}/M_{jk}^{World}\right)$			0.135 (0.137)	
Quintile4* $\Delta\left(M_{jk}^{China}/M_{jk}^{World}\right)$			0.272** (0.124)	
Highest Quintile 5 of (ICT/ N)$_{t-5}$* $\Delta\left(M_{jk}^{China}/M_{jk}^{World}\right)$			0.201 (0.138)	
(ICT/ N)$_{t-5}$ PCs per worker at (t-5)	0.001 (0.006)	-0.002 (0.006)		
ln(N)$_{t-5}$ Log(Employment) at (t-5)	-0.038*** (0.002)	-0.038*** (0.002)	-0.038*** (0.002)	0.039*** (0.002)
Quintile 1 Lowest Quintile of PCs per worker at (t-5)				-0.018*** (0.006)
Country Year effects	Yes	Yes	Yes	Yes
SiteType Controls	Yes	Yes	Yes	Yes
Observations	28,624	28,624	28,624	28,624

Notes: *** denotes 1% significance; ** denotes 5% significance; * denotes 10% significance. Estimation is by OLS with standard errors clustered by country (k) - four digit industry (j) pair in parentheses. There are 2,863 country-industry clusters for columns (1)-(4) and 2,225 for column (5). SURVIVAL refers to whether an establishment that was alive in 2000 was still alive in 2005 for the HH-Amatech sample. $\Delta\left(M_{jk}^{China}/M_{jk}^{World}\right)$ represents the 5-year difference in Chinese imports as a fraction of total imports in a four-digit industry by country pair. Quintiles represent bands of establishments ordered from highest (5) to the lowest (1) in terms of their baseline PC intensity, (ICT/ N) t-5. Note that linear quintile terms are included in the column (3) regression but not reported in the table. Countries include Austria, Denmark, Finland, France, Germany, Italy, Norway, Spain, Sweden, Switzerland and the UK. Site type controls are dummies for establishment type and include Divisional HQ, a Divisional Branch, an Enterprise HQ or a Standalone Branch. “Number of Firms” is defined as number of establishments for Panel (A) and the number of companies for panel (B).

APPENDIX A - ADDITIONAL TABLES

TABLE A1: FIRST STAGE REGRESSIONS OF UK ICT INTENSITY ON US ICT INTENSITY.

	(A) Period I – 1998-2001				(B) Period II – 2002-2006			
	Manuf	Services	Manuf	Services	Manuf	Services	Manuf	Services
US ICT	0.80***	0.58***	0.51***	0.68***	0.39***	0.60***	0.47***	0.52***
US PC Intensity	0.067	0.088	0.080	0.100	0.14	0.069	0.073	0.091
Transport			-0.083	0.36	-0.97			0.61
Share of Inputs from Transport			0.14	0.33	1.32			0.45
Manufacturing			-0.21*	0.011	-1.09			0.060
Share of inputs from Manuf			0.12	0.087	1.34			0.12
Services			0.18	-0.36*	-0.76			0.030
Share of inputs from services			0.12	0.19	1.32			0.20
Own IO				0.069	-0.32**			0.016
Own industry input share				0.091	0.16			0.12
EG				-0.039	-2.07			-0.11
				0.25	3.19			0.28
Skill				0.39**	0.014			0.38**
Share of Degree Educated Workers				0.17	0.24			0.16
Number of Observations	88	84	188	84	69	88	86	84

Notes: ***, ** and * indicate significance at the 1%, 5% and 10% levels, respectively. Standard errors reported below coefficients are robust to arbitrary heteroscedasticity.

TABLE A2: FIRST STAGE REGRESSIONS OF UK ICT INTENSITY ON US ICT INTENSITY (FIXED EFFECTS).

	(A) No Additional Controls		(B) Additional Controls	
	Manufacturing	Services	Manufacturing	Services
US ICT	0.11	0.090	0.29	0.49*
US PC Intensity	0.095	0.16	0.17	0.28
Transport			0.32	1.35
Share of Inputs from Transport			1.00	4.93
Manufacturing			0.36*	2.66
Share of inputs from Manuf			0.21	4.70
Services			0.36	-0.11
Share of inputs from services			0.26	5.11
Own IO			0.062	0.13
Own industry input share			0.18	0.57
EG			-2.10**	1.12
			0.97	7.81
Skill			-0.049	0.59
Share of Degree Educated Workers			0.12	0.37
Observations	177	172	168	142
Number of Groups	89	86	87	72

Notes: ***, ** and * indicate significance at the 1%, 5% and 10% levels, respectively. Standard errors reported below coefficients are robust to arbitrary heteroscedasticity.

TABLE A3: DESCRIPTIVE STATISTICS FOR US UNIVERSITY PATENTS.

Panel A: Patent Variables

Variable:	Mean	Median	Std. Dev.	Min	Max
Number of Forward Citations	14.87	8	22.33	1	500
Grant Year of Cited Patent	1995	1996	6.36	1976	2006
Grant Year of Citing Patent	2001	2002	4.41	1979	2007
Citation Lag	6.0	5	3.72	0	31
Distance, miles	1217.8	1128.6	792.02	0	3276

Panel B: Location Dummies

Dummy Variable:	Share of Citations	No. of Universities	Share Private Univ.	No. Cited Patents	No. Citing Patents
Dummy for within-State	0.20	76	0.52	7,539	62,981
Dummy for Distance < 25	0.13	76	0.54	5,301	48,394
Dummy for 25 ≤ Distance < 50	0.02	53	0.60	1,718	22,308
Dummy for 50 ≤ Distance < 100	0.01	57	0.56	1,021	14,985
Dummy for 100 ≤ Distance < 150	0.01	60	0.59	1,091	6,183
Dummy for 150 ≤ Distance < 250	0.33	63	0.62	2,553	29,185
Dummy for 250 ≤ Distance < 500	0.07	73	0.57	5,440	48,039
Dummy for 500 ≤ Distance < 1000	0.10	77	0.44	7,060	49,705
Dummy for Distance ≥ 1000	0.21	77	0.50	12,696	54,520

Notes: This table reports summary statistics for university cited patents. The dummy for IPC match takes the value of one for citations where the citing and cited patent share the same 4-digit IPC and zero otherwise. Dummies for distance intervals refer to the distance in miles between the location of the citing inventor and the cited university. Panel B reports summary statistics for location dummies. A citation is within-state if the citing inventor resides in the same state as the cited university.

TABLE A4: MEAN COMPARISON TESTS: DISTANCE AND STATE-BORDER EFFECTS.

		Panel A: Distance from cited University				*Panel B: Within-state citations*			
Universities:	# Pairs	Mean for citing patents	Mean for controls	Diff. in means	t-stat diff. equals zero	Mean for citing patents	Mean for controls	Diff. in means	t-stat diff. equals zero
All	129,483	1,344.7	1,426.3	-6.1%	-20.1***	0.163	0.075	53.9%	69.6***
Private	69,860	1,401.7	1,458.1	-4.0%	-9.5***	0.170	0.089	47.9%	45.6***
Public	59,623	1,277.8	1,389.1	-8.7%	-20.5***	0.154	0.059	61.6%	53.9***
Weak Local Objectives	44,744	1,421.0	1,488.1	-4.7%	-8.9***	0.170	0.080	53.1%	41.3***
Strong Local Objectives	41,270	1,313.6	1,425.6	-8.5%	-16.2***	0.177	0.086	51.5%	39.2***
Weak State Constraints	80,943	1,357.8	1,418.4	-4.5%	-11.4***	0.166	0.082	50.6%	51.7***
Strong State Constraints	48,540	1,322.7	1,439.6	-8.8%	-18.6***	0.157	0.063	59.6%	47.2***
Land Grant	53,970	1,363.4	1,457.5	-6.9%	-14.8***	0.158	0.069	56.3%	46.6***
No Land Grant	75,513	1,331.2	1,404.0	-5.5%	-13.8***	0.166	0.079	52.3%	51.8***

Notes: This table reports mean comparison tests between actual and control citations for distance from the cited university (Panel A) and within-state dummy (Panel B). Control citations are constructed in the following way. For each citation to a university patent, we select a control patent in the same 4-digit IPC and with grant year as close as possible to the citing patent. Strong constraints are defined as cases where the university reports that at least three constraints are either moderately or very important. The sample average probability of citations is 50 percent, by construction. * significant at 10%; ** significant at 5%; *** significant at 1%.

TABLE A5: TAXONOMY OF BUSINESS INTANGIBLES.

Type	*Comments on Evidence as Capital Spending*	*Data Used*
1. Computerised information (mainly computer software)	Firms capitalise only a fraction of purchased software in financial accounts. Relatively little is known about the service life of software assets.	Uses business investment in software series form National Income and product Accounts (NIPA)
2. Innovative Property		
(a) Scientific R&D	Research suggests that scientific R&D yields relatively long-lasting returns and is capital spending.	National Science Foundation (NSF)
(b) Non-scientific R&D	Little is known about non-scientific R&D but a portion of new product development expenditures in the entertainment industry apparently have relatively short-lived effects.	
3. Economic Competencies		
(a) Brand equity	Research shows that the effects of some advertising dissipate within one year, but that more than half has effects that last more than one year.	Coen report for Universal-McCann.
(b) Firm-specific resources	Research suggests that firm-specific training is investment. Spending for organisational change is also likely to have long-lived effects, but a portion of management fees is probably not capital spending.	Bureau Labor Statistics (BLS) employer training expenditure.

Source: Corrado, Hulten and Sichel (2006).

TABLE A6: FULL LIST OF MANAGEMENT PRACTICES WITH EXAMPLES OF QUESTIONS.

Practice	Practice number	Practice type	Example of questions we asked
Modern manufacturing, introduction	1	Operations	a) Can you describe the production process for me? b) What kinds of lean (modern) manufacturing processes have you introduced? Can you give me specific examples? c) How do you manage inventory levels? What is done to balance the line?
Modern manufacturing, rationale	2	Operations	a) Can you take through the rationale to introduce these processes? b) What factors led to the adoption of these lean (modern) management practices?
Process documentation	3	Operations	a) How would you go about improving the manufacturing process itself? b) How do problems typically get exposed and fixed? c) Talk me through the process for a recent problem. d) Do the staff ever suggest process improvements?
Performance tracking	4	Monitoring	a) Tell me how you track production performance? b) What kind of Key Performance Indicators (KPIs) would you use for performance tracking? How frequently are these measured? Who gets to see this KPI data? c) If I were to walk through your factory could I tell how you were doing against your KPI's?
Performance review	5	Monitoring	a) How do you review your Key Performance Indicators (KPIs)? b) Tell me about a recent meeting. Who is involved in these meetings? c) Who gets to see the results of this review?
Performance dialogue	6	Monitoring	a) How are these meetings structured? Tell me about your most recent meeting. b) During these meeting, how much useful data do you have? c) How useful do you find problem solving meetings? d) What type of feedback occurs in these meetings?
Consequence management	7	Monitoring	a) What happens if there is a part of the business (or a manager) who isn't achieving agreed upon results? Can you give me a recent example? b) What kind of consequences would follow such an action? c) Are there are any parts of the business (or managers) that seem to repeatedly fail to carry out agreed actions?
Target breadth	8	Targets	a) What types of targets are set for the company? What are the goals for your plant? b) Tell me about the financial and non-financial goals? c) What do Company Head Quarters (CHQ) or their appropriate manager emphasise to you?
Target interconnection	9	Targets	a) What is the motivation behind your goals? b) How are these goals cascaded down to the individual workers? c) What are the goals of the top management team (do they even know what they are!)? d) How are your targets linked to company performance and their goals?

Target time horizon	10	Targets	a) What kind of time scale are you looking at with your targets? b) How are long term goals linked to short term goals? c) Could you meet all your short-run goals but miss your long-run goals?
Targets are stretching	11	Targets	a) How tough are your targets? Do you feel pushed by them? b) On average, how often would you say that you meet your targets? c) Are there any targets which are obviously too easy (will always be met) or too hard (will never be met)? d) Do you feel that on targets that all groups receive the same degree of difficulty? Do some groups get easy targets?
Performance clarity and comparability	12	Monitoring	a) What are your targets (i.e. do they know them exactly)? Tell me about them in full. b) Does everyone know their targets? Does anyone complain that the targets are too complex? c) How do people know about their own performance compared to other people's performance?
Managing human capital	13	Targets	a) Do senior managers discuss attracting and developing talented people? b) Do senior managers get any rewards for bringing in and keeping talented people in the company? c) Can you tell me about the talented people you have developed within your team? Did you get any rewards for this?
Rewarding high performance	14	Incentives	a) How does you appraisal system work? Tell me about the most recent round? b) How does the bonus system work? c) Are there any non-financial rewards for top-performers?
Removing poor performers	15	Incentives	a) If you had a worker who could not do his job what would you do? Could you give me a recent example? b) How long would underperformance be tolerated? c) Do you find any workers who lead a sort of charmed life? Do some individuals always just manage to avoid being fixed/fired?
Promoting high performers	16	Incentives	a) Can you rise up the company rapidly if you are really good? Are there any examples you can think of? b) What about poor performers – do they get promoted more slowly? Are there any examples you can think of? c) How would you identify and develop (i.e. train) your star performers? d) If two people both joined the company 5 years ago and one was much better than the other would he/she be promoted faster?
Attracting human capital	17	Incentives	a) What makes it distinctive to work at your company as opposed to your competitors? b) If you were trying to sell your firm to me how would you do this (get them to try to do this)? c) What don't people like about working in your firm?
Retaining human capital	18	Incentives	a) If you had a star performer who wanted to leave what would the company do? b) Could you give me an example of a star performers being persuaded to stay after wanting to leave? c) Could you give me an example of a star performer who left the company without anyone trying to keep them?

TABLE A7: DETAILS OF THE DECENTRALISATION SURVEY QUESTIONS.

For Questions D1, D3 and D4 any score can be given, but the scoring guide is only provided for scores of 1, 3 and 5.

Question D1: “*To hire a FULL-TIME PERMANENT SHOPFLOOR worker what agreement would your plant need from CHQ (Central Head Quarters)?”*

Probe until you can accurately score the question – for example if they say “*It is my decision, but I need sign-off from corporate HQ.*” ask “*How often would sign-off be given?*”

	Score 1	Score 3	Score 5
Scoring grid:	No authority – even for replacement hires	Requires sign-off from CHQ based on the business case. Typically agreed (i.e. about 80% or 90% of the time).	Complete authority – it is my decision entirely

Question D2: “*What is the largest CAPITAL INVESTMENT your plant could make without prior authorisation from CHQ?*”

Notes: (a) Ignore form-filling

(b) Please cross check any zero response by asking “*What about buying a new computer – would that be possible?”*, and then probe….

(c) Challenge any very large numbers (e.g. >$¼m in US) by asking “*To confirm your plant could spend $X on a new piece of equipment without prior clearance from CHQ?*”

(d) Use the national currency and do not omit zeros (i.e. for a US firm twenty thousand dollars would be 20000).

Question D3: “*Where are decisions taken on new product introductions – at the plant, at the CHQ or both”*?

Probe until you can accurately score the question – for example if they say “*It is complex, we both play a role* “ask “*Could you talk me through the process for a recent product innovation?*”

	Score 1	Score 3	Score 5
Scoring grid:	All new product introduction decisions are taken at the CHQ	New product introductions are jointly determined by the plant and CHQ	All new product introduction decisions taken at the plant level

Question D4: “*How much of sales and marketing is carried out at the plant level (rather than at the CHQ)”*?

Probe until you can accurately score the question. Also take an average score for sales and marketing if they are taken at different levels.

	Score 1	Score 3	Score 5
Scoring grid:	None – sales and marketing is all run by CHQ	Sales and marketing decisions are split between the plant and CHQ	The plant runs all sales and marketing

Question D5: “*Is the CHQ on the site being interviewed”*?

Question D6: “How much do managers decide how tasks are allocated across workers in their teams”

	Score 1	Score 2	Score 3	Score 4	Score 5
Interviewers are read out the following five options, with our scoring for these note above:	All managers	Mostly managers	About equal	Mostly workers	All workers

Question D7: “Who decides the pace of work on the shopfloor”

	Score 1	Score 2	Score 3	Score 4	Score 5
Interviewers are read out the following five options, with “customer demand” an additional not read-out option	All managers	Mostly managers	About equal	Mostly workers	All workers

Question D8: “How many people directly report to the PLANT MANAGER (i.e. the number of people the PLANT MANAGER manages directly in the hierarchy below him)?

Note: cross-check answers of X above 20 by asking “So you directly manage on a daily basis X people?”

APPENDIX B – BACKGROUND TABLES

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: AMATECH NAME MATCHES.

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 automatic and manual name matching, current as at November 2009. Excludes all public sector establishments.

TABLE B4: 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 B5: 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 (2008), in turn based on Stiroh (2002). 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 B6: 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 B7: 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

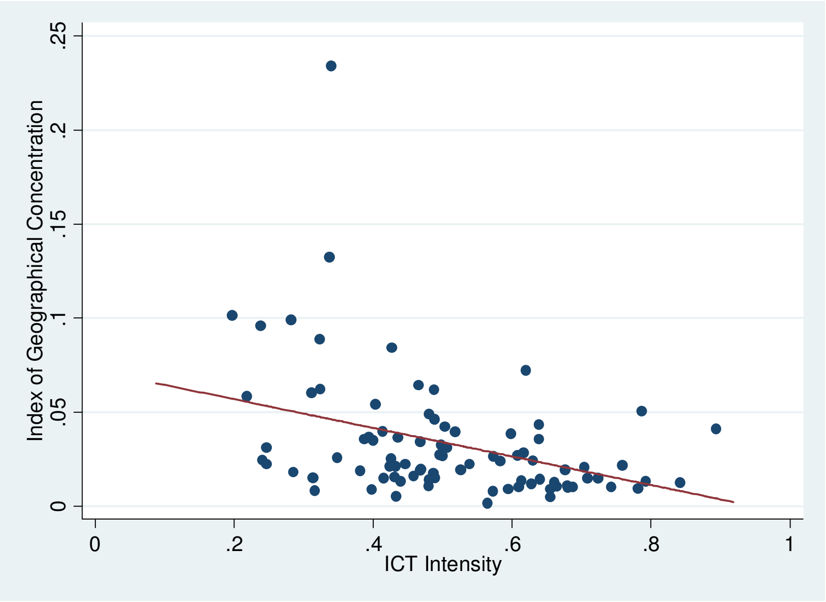
Source: van Ark, Mahoney and Timmer (2008). Estimates based on the Groningen Growth and Development Centre, Total Economy Database.

TABLE B8: 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

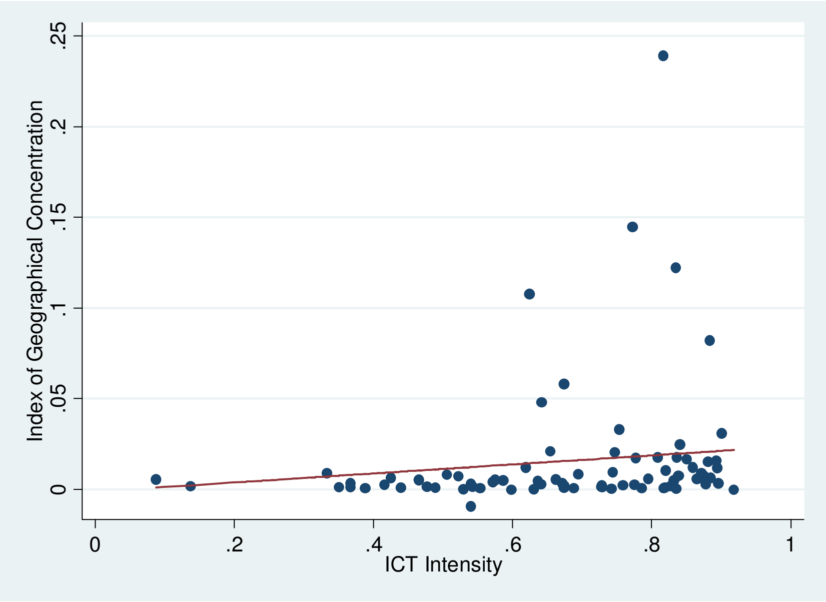
Source: van Ark, Mahoney and Timmer (2008). Calculations based on the EU KLEMS database. Column (1) is the sum of the components in columns (1)-(5). European Union aggregate refers to the ten countries covered in the table.

FIGURE 1: GEOGRAPHICAL CONCENTRATION AND ICT INTENSITY IN MANUFACTURING (UK, 1998-2006).



Notes: The figure plots the EG index of geographical concentration against ICT for 3 digit SIC manufacturing industries. The line gives the fitted values from a regression of the index on a constant and ICT.

FIGURE 2: GEOGRAPHICAL CONCENTRATION AND ICT INTENSITY IN SERVICES, (UK, 1998-2006).



Notes: The figure plots the EG index of geographical concentration against ICT for 3 digit SIC service industries. The line gives the fitted values from a regression of the index on a constant and ICT**.**

FIGURE 3a: PEOPLE MANAGEMENT Z-SCORES, ALL FIRMS BY COUNTRY OF LOCATION.

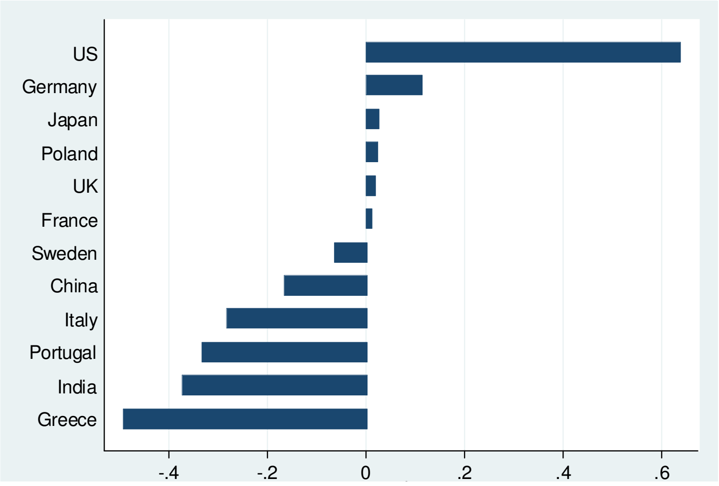
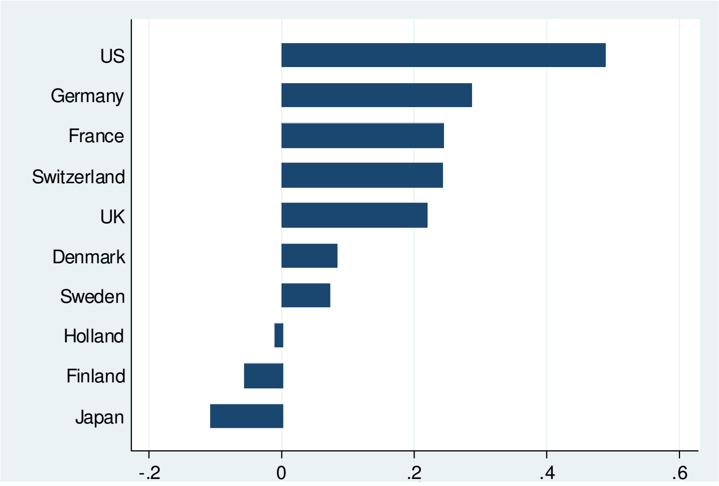
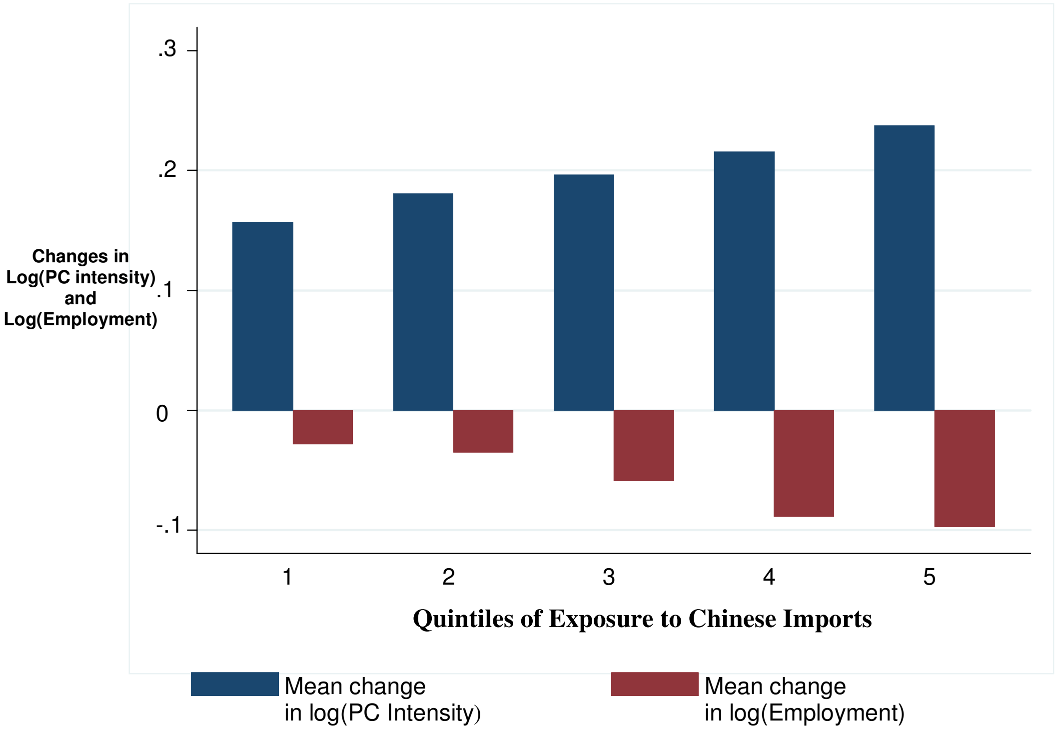


FIGURE 3b: PEOPLE MANAGEMENT Z-SCORES, MULTINATIONALS BY COUNTRY OF ORIGIN.



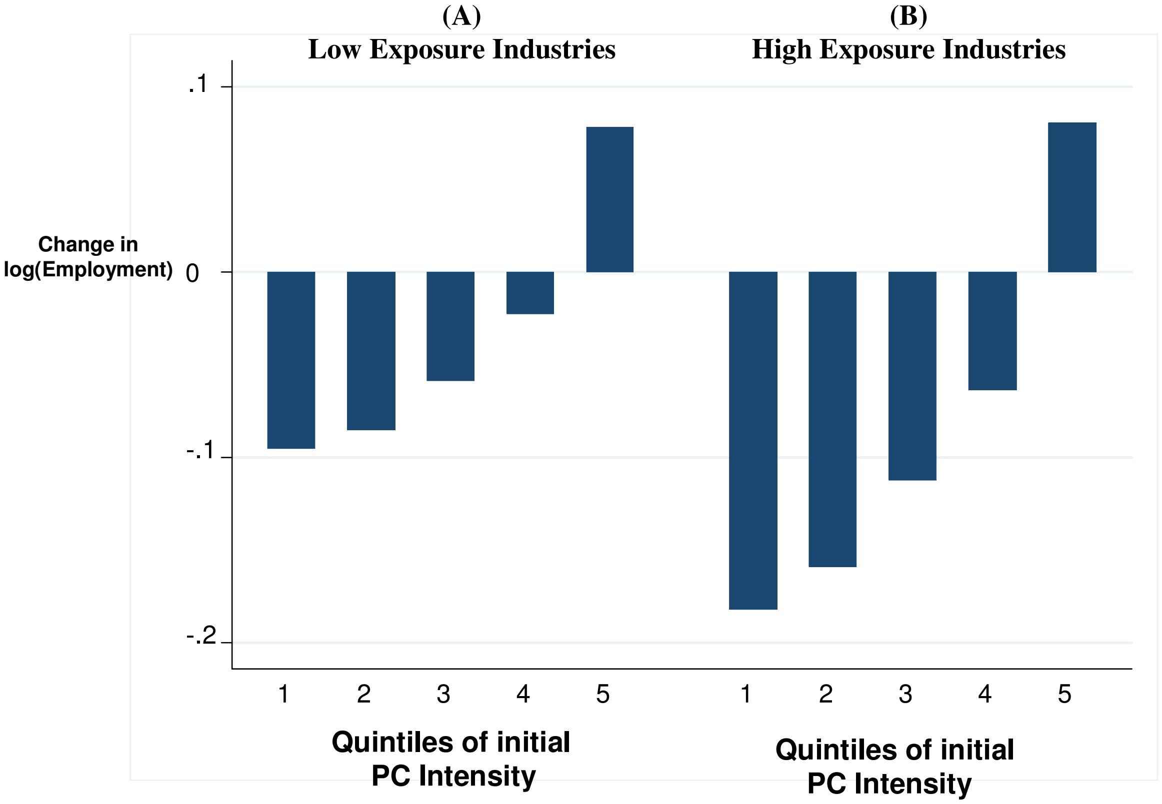
Notes: In Figures 3a and 3b the “People management z-score” is the average z-score score for the 4 management practices on people management, covering “Managing human capital”, “Rewarding high performance”, Removing poor performers” and “Promoting high performers”. This is normalized to have a firm level standard deviation of 1. The sample in Figure 3a is all 4,003 firms sorted according to country of location. The sample in Figure 3b is the subset of 631 multinational subsidiaries located in France, Germany, Italy, Poland, Portugal, Sweden and the UK, sorted according to country of origin and only plotted for origin countries with at least 25 firms in the sample.

FIGURE 4: CHANGES IN PC INTENSITY AND EMPLOYMENT BY EXPOSURE TO CHINESE IMPORTS, EUROPEAN ESTABLISHMENTS 2000-2006



Notes: Calculated using regression sample of 27,354 observations for two waves of 5-year differences occurring in 2005 and 2006. The “Quintiles of Exposure to Chinese Imports” along the horizontal axis are classified according to the distribution of $\Delta\left(M_{jk}^{China} / M_{jk}^{World}\right)$, the 5-year difference in Chinese imports as a fraction of total imports in a four-digit industry by country pair. The quintiles are ordered from 1 (lowest exposure) to 5 (highest exposure). The vertical axis measures $\Delta \ln(IT / N)$, the 5-year change in log (PCs per worker) and $\Delta \ln(N)$, the 5 year change in log (Employment).

FIGURE 5: CHANGES IN LOG(EMPLOYMENT) BY INITIAL PC INTENSITY 2000-2006, HIGH VERSUS LOW EXPOSURE INDUSTRIES



Notes: Calculated using regression sample of 27,354 observations for 2005 and 2006. "Low Exposure" industries in panel (A) defined as observations falling in the lowest quintile (1) of the distribution of $\Delta\left(M_{jk}^{China} / M_{jk}^{World}\right)$, the 5-year difference in Chinese imports as a fraction of total imports in a four-digit industry by country pair. "High exposure" industries in panel (B) defined as observations classified in the highest quintile (5) of $\Delta\left(M_{jk}^{China} / M_{jk}^{World}\right)$. The horizontal axis then classifies observations according to (ICT/ N) $_{t-5}$ their initial level of PC intensity, going from lowest (1) to highest (5).

APPENDIX C – BACKGROUND INFORMATION

I ADDITIONAL ISSUES IN PRODUCTIVITY ESTIMATION

There are many problems involved in estimating the production function for ICT. Some of these are generic issues related to the estimation of production functions that have been alluded to in the main text of the report. For instance, unobserved heterogeneity: there are many factors correlated with productivity that we do not measure. If unobserved heterogeneity is constant over time then panel data can help. The unobserved factor can be treated as a fixed effect and then the estimation can proceed with either dummy variables for each firm (within groups) being included, or by differencing the data (for example, first differences). Another problem is endogeneity. The factor inputs (such as ICT) are chosen by firms and are not, therefore, exogenous when included on the right-hand side of the production function. One solution to this is to find external instruments that affect the decision to invest in ICT, but do not affect the productivity of the firm directly.

The literature has not followed up this solution, however, and most studies ignore these issues and simply estimate production using ordinary least square (OLS) methods. However, some advanced studies examine various approaches for dealing with these problems, with some (Stiroh 2004; Bloom, Sadun, and Van Reenen 2007) actually comparing the results derived across these approaches. Below we discuss three approaches: TFP-based, General Method of Moment (GMM), and Olley Pakes (OP).

(i) TFP-based approaches

A common approach in the ICT literature dealing with this issue is to consider a transformation that constructs a measured TFP growth term. For example, Brynjolffson and Hitt (2003) estimate the following forms of equations:

$$\Delta \tilde{a} = \beta_1 \Delta c \tag{1}$$

where the dependent variable is measured TFP (or 'four factor' TFP')

$$\Delta \tilde{a} = \Delta y - s_l \Delta l - s_k \Delta k - s_c \Delta c - s_m \Delta m \tag{2}$$

If ICT earned 'normal returns' then the coefficient β_1 =0. Unfortunately, although this resolves the endogeneity problem for the non-ICT factor inputs by moving them from the right-hand side to the left-hand side of the equation, the endogeneity of ICT remains a problem. In fact, it is likely to be exacerbated as the construction of measured TFP involves the variable of interest on the right-hand side of the equation. Any measurement error in ICT will be transmitted into a biased coefficient on β_1.

An additional problem is that classical measurement errors in ICT will generate an attenuation bias towards zero for β_1. This is one reason for turning to longer differenced models, the approach adopted by Brynjolffson and Hitt (2003) (although they interpret their increasing coefficients as being due to unmeasured organisational capital rather than measurement error. In general, the attenuation bias should be less for longer differences than for shorter differences as the transitory shocks will be averaged out increasing the signal to noise ratio for the ICT measure

(Griliches and Hausman 1986) Again, however, there is no free lunch. Although this reduces the random measurement error, endogeneity problems are exacerbated because the transformed error term now includes more time periods.

(ii) General Method of Moment (GMM) Approaches

The key contribution of GMM approaches in this context is the ability of these methods to generate "internal" instruments using appropriately lagged input variables. For notational simplicity, re-consider the basic production function as:

$$y_{it} = \theta x_{it} + u_{it} \tag{3}$$

where θ is the parameter of interest. Assume that the error term, uit, takes the form

$$u_{it} = \eta_i + \tau_t + \omega_{it} \tag{4a}$$

$$\omega_{it} = \rho \omega_{it-1} + v_{it} \tag{4b}$$

τ_t represents macro-economic shocks captured by a series of time dummies, η_i is an individual effect, and v_{it} is a serially uncorrelated mean zero error term. The other element of the error term, ω_{it} is allowed to have an AR(1) component (with coefficient ρ), which could be the result of measurement error or slowly evolving technological change. Substituting (4a) into (3) gives the dynamic equation:

$$y_{it} = \pi_1 y_{it-1} + \pi_2 x_{it} + \pi_3 x_{it-1} + \eta^*{}_i + \tau^*{}_t + v_{it} \tag{5}$$

The common factor restriction (COMFAC) is $\pi_1 \pi_2 = -\pi_3$. Note that $\tau^*{}_t = \tau_t - \rho \tau_{t-1}$ and ηi*= (1-ρ)ηi .

Blundell and Bond (2000) recommend a system GMM approach to estimate the production function and impose the COMFAC restrictions by minimum distance. If we allow inputs to be endogenous, we will require instrumental variables. In the absence of any obvious natural experiments, we consider moment conditions that will enable us to construct a GMM estimator for equation (5). A common method is to take first differences of (5) to sweep out the fixed effects:

$$\Delta y_{it} = \pi_1 \Delta y_{it-1} + \pi_2 \Delta x_{it} + \pi_3 \Delta x_{it-1} + \Delta \tau_t + \Delta v_{it} \tag{6}$$

Since v_{it} is serially uncorrelated the moment condition:

$$E(x_{it-2} \Delta v_{it}) = 0 \tag{7}$$

ensures that instruments dated t-2 and earlier are valid and can be used to construct a GMM estimator for equation (4) in first differences (Arellano and Bond 1991). A problem with this estimator is that variables with a high degree of persistence over time (such as capital) will have very low correlations between their first difference (Δx_{it}) and the lagged levels being used an instrument (for example, x_{it-2}). This problem of weak instruments can lead to substantial bias in finite samples. Blundell and Bond (1998) point out that under a restriction on the initial conditions another set of moment conditions is available[74]:

$$E(\Delta x_{it-1}(\eta_i + v_{it})) = 0 \tag{8}$$

This implies that lags of first differences of the endogenous variables can be used to control for the levels in equation (5) directly. The econometric strategy is to combine the instruments implied by the moment conditions (7) and (8). We can obtain consistent estimates of the coefficients and use these to recover the underlying structural parameters.

(ii) The Olley-Pakes method

Reconsider the basic production function as:

$$y_{it} = \alpha_l l_{it} + \alpha_m m_{it} + \alpha_k k_{it} + \alpha_c c_{it} + \omega_{it} + \eta_{it} \tag{9}$$

The efficiency term, ω_{it}, is the unobserved productivity state that will be correlated with both output and the variable input decision, and η_{it} is an independent and identically distributed (i.i.d) error term. Assume that both capital stocks are predetermined and current investment (which will react to productivity shocks) takes one period before it becomes productive, that is:

$I_{it}^{K} = I_{t-1}^{K} + (1-\delta^{K})K_{it-1}$ and $I_{it}^{C} = I_{t-1}^{C} + (1-\delta^{C})C_{it-1}$.

It can be shown that the investment policy functions for ICT and non-ICT are monotonic in non-ICT capital, ICT capital, and the unobserved productivity state.

$$i_{it}^{K} = i^{K}(k_{it}, c_{it}, \omega_{it}) \tag{10}$$

$$i_{it}^{C} = i^{C}(k_{it}, c_{it}, \omega_{it}) \tag{11}$$

The investment policy rule, therefore, can be inverted to express ω_{it} as a function of investment and capital. Focusing on the non-ICT investment policy function it can be inverted to obtain the proxy: $\omega_t^K(i_{it}^K, k_{it}, c_{it})$. The first stage of the OP algorithm uses this invertibility result to re-express the production function as:

$$\begin{aligned} y_{it} &= \alpha^{L} l_{it} + \alpha^{M} m_{it} + \alpha^{K} k_{it} + \alpha^{C} c_{it} + \omega_t^{K}(i_{it}^{K}, k_{it}, c_{it}) + \eta_{it} \\ &= \alpha^{L} l_{it} + \alpha^{M} m_{it} + \phi(i_{it}^{K}, k_{it}, c_{it}) + \eta_{it} \end{aligned} \tag{12}$$

where $\phi(i_{it}^K, k_{it}, c_{it}) = \phi_t = \omega_t^K(i_{it}^K, k_{it}, c_{it}) + \alpha^K k_{it} + \alpha^K c_{it}$

We can approximate this function with a series estimator or non-parametric approximation and use this first stage results to get estimates of the coefficients on the variable inputs. The second stage of the OP algorithm is:

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[74] The conditions are that the initial change in productivity is uncorrelated with the fixed effect $E(\Delta y_{i2}\eta_i) = 0$ and that initial changes in the endogenous variables are also uncorrelated with the fixed effect $E(\Delta x_{i2}\eta_i) = 0$.

$$y_{it}* = y_{it} - \alpha^L l_{it} - \alpha^M m_{it} = \alpha^K k_{it} + \alpha^C c_{it} + \omega_{it} + \eta_{it} \quad (13)$$

Note that the expectation of productivity, conditional on the previous period's information set (denoted Ωt-1) is:

$$\omega_{it} \mid_{\chi_{it}=1} = E[\omega_{it} \mid \omega_{it-1}, \chi_{it} = 1] + \xi_{it} \quad (14)$$

where $\chi_{it} = 1$ indicates that the firm has chosen not to shut down (a selection stage over the decision to exit can be incorporated in a straightforward manner). This expression for productivity state is based on the assumption that unobserved productivity evolves as a first order Markov process. Again, we assume that we can approximate this relationship with a high order series approximation g (ω_{it-1}). Substituting this in to the second stage, and making expectations conditional on the previous period's information set gives:

$$E(y_{it}* \mid \Omega_{t-1}) = \alpha^K k_{it} + \alpha^C c_{it} + g[\phi(i^K_{it-1}, k_{it-1}, \alpha^C c_{it-1}) - \alpha^K k_{it-1} - \alpha^C c_{it-1}] \quad (15)$$

Since we already have estimates of the ϕ_{t-1} function this amounts to estimating by Non-Linear Least Squares (NLLS). We now have all the relevant parameters of the production function.

Numerous extensions to the basic OP methodology have been suggested. First, we consider the additional selection correction originally suggested by the authors. Second, Levinsohn and Petrin (2003) suggest using intermediate inputs as an alternative proxy for the unobserved productivity term. This has attractions for plant level data where investment is zero in a non-trivial number of cases. Ackerberg, Caves, and Frazer (2005) and Bond and Soderbom (2005) emphasise the identification problems underlying the original OP set up, which implicitly requires variation in firm specific input prices. Bond and Soderbom argue for the GMM approach discussed in the previous sub-Section, which is identified in the presence of differential adjustment costs.

II MEASURING ICT CAPITAL

In this Section we describe the basic issues involved in constructing measures of ICT capital. The ideal measure capturing the economic contribution of capital inputs in a production theory context is flow of capital services. Building this variable from raw data entails non trivial assumptions regarding: a) the measurement of the investment flows in the different assets; and b) the aggregation over vintages of a given type of asset. Assuming for the moment that we can measure investments in the specific asset without error, we investigate point b).

For the sake of simplicity we assume a framework in which only one type of capital is used for production. Output will depend on the aggregation of the different vintages of investments made over the years, after allowing for the fact that the capacity of earlier investments decays after installation. Defining the decay factor for an investment of s years old d_s, and I_{t-s} as the real gross investment of vintage s, the aggregate capital stock can be written as:

$$K_t = \sum_{s=0}^{n} (1 - d_s) I_{t-s} \quad (16)$$

If we assume that the rate of decay is constant over time (geometric rate of decay), then Equation 1 takes the very simple form:

$$K_t = I_t + (1-d)K_{t-1} \tag{17}$$

In the case of geometric decay, the rate of decay is equal to the depreciation rate (δ) (Oulton and Srinivasan 2003). Depreciation measures the difference between the price of a new and a one-year old asset at time t. Defining the price of a specific asset of age j at time s as $p_{s,j}$, then the depreciation rate is:

$$\delta_t = \frac{(p_{t,j} - p_{t,j+1})}{p_{t,j}} \tag{18}$$

Assuming that the depreciation rate of the asset does not vary over time we can omit the time subscript. A concept related to depreciation rate is the capital gain/loss (f) associated with the investment in the specific asset. The capital gain/loss is defined as the change in the price of a new asset between periods t-1 and t, that is:

$$f_{t,j} = (p_{t,j} - p_{t-1,j}) \tag{19}$$

Both depreciation and capital gain/loss affect the definition of a very important capital measurement theory concept, rental price $(\rho_{t,j})$ for the capital services of a capital input of age j at time t. This is defined as:

$$\rho_{t,j} = r_t \cdot p_{t-1,j} + \delta \cdot p_{t,j} - f_{t,j} \tag{20}$$

where r_t is the actual nominal rate of return during period t. The rental price is what the company would pay if instead of buying the capital good, it rents it from another firm. A profit maximising firm will hire the capital good up to the point when the rental price equals the marginal revenue of the product of the capital good. Under perfect competition, the rental price will be equal to the value of the marginal product of the asset. In this case, the asset is said to deliver normal returns. When the marginal product is higher than the rental price, then the asset is said to deliver excessive returns.

The challenge for work using firm level data lies in translating the above ideal framework into practical elements. We follow the approach that was used in the leading early studies that were based on firm level equipment data. In Brynjolfsson, Bresnahan, and Hitt (2002) the nominal values are deflated using price information developed by Robert Gordon (19.3% yearly changes). Also in Brynjolfsson and Hitt (2003) the data are transformed from wealth stocks (market value of the assets) into productive stock (the value of assets based on output capability) multiplying the wealth stocks by the annual aggregate ratio of the productive stock to the wealth stock of computer assets computed by the Bureau of Labor Statistics.

III ECONOMETRIC MODEL FOR PRODUCT AND PROCESS INNOVATION

The estimation approach in this report fully implements the framework put forward by Athey and Stern (1998). This is the first time that the adoption approach (based on innovation profiles of firms) and the productivity approach (based on the actual return of each strategy) are integrated in a single estimation procedure. The estimation makes use of information on profits associated with each scale decision and innovation profile of each firm. This introduces several restrictions on unobservables that are sufficient to produce meaningful estimates that control for unobserved heterogeneity. Innovation indicators are dummy variables indicating adoption of particular software as described above. This adds to the complexity of the estimation, but accurately reflects the discrete nature of innovation decisions, especially their adoption. In addition, and to deal with the important effects of unobserved returns to each strategy, we assume them to be jointly normally distributed so that we can evaluate how the unobserved heterogeneity associated with implementing each strategy, —i.e., unobserved, strategy specific returns— affects the profitability of the rest of the strategies. As Athey and Stern (1998, §4.2) point out, allowing for an unrestricted variance-covariance matrix of the distribution of these unobserved returns "provides a parsimonious specification that still accommodates the main alternative hypothesis regarding complementarity among strategies and the role of unobserved heterogeneity."

The following econometric model allows us to disentangle these two sources of interlinked adoption decisions and test whether complementary relationships play any (significant) role in decisions regarding innovation adoption.

We write the profit function of firm i as:

$$\pi_i(x_{di},x_{ci},x_{yi}) = \theta_{\pi i} + \varepsilon_{\pi i} + (\theta_{di}+\varepsilon_{di})x_{di} + (\theta_{ci}+\varepsilon_{ci})x_{ci} + (\theta_{yi}+\varepsilon_{yi})x_{yi} + \delta_{dc}x_{di}x_{ci} + \delta_{dy}x_{di}x_{yi} + \delta_{cy}x_{ci}x_{yi} + (\gamma/2)x_{yi}^2 \qquad (21)$$

This is a general approximation to the profit function which imposes very little structure on the underlying production technology. It is quadratic in scale x_{yi} and the adoption of innovations is represented by two dichotomous variables, x_{di} and x_{ci}. It also includes interaction terms among all these strategies — parameters δ_{dc}, δ_{dy}, and δ_{cy}— whose estimated signs determine whether the profit function is supermodular or submodular in each pair of strategies. No assumptions are made about these potentially complementary relations and our estimates will determine them regardless of whether the strategies are continuous, such as the scale, or discrete, as in the case of innovations. We envision firm i choosing its scale and innovation profile in order to maximise the profit function $\pi_i(x_{di},x_{ci},x_{yi})$. For the solution of this problem to be well defined we only need to assume that equation (1) is concave on the xyi dimension. An important goal of the econometric estimation is to determine whether the estimates of δ_{dc}, δ_{dy}, and δ_{cy} are significantly different from zero, or alternatively, if the correlations are due to the existence of other observed or unobserved elements of the environment of the firm for which we do not have information. The existence of returns that are observed by firms but not by econometricians explains why firms with identical observable characteristics (θ_{di}, θ_{ci}, and θ_{yi}) may end up choosing different strategies (x_{di},x_{ci},x_{yi}) and reaching different profit levels, π_i. Therefore, the return of each strategy, i.e., its direct impact on profits, includes an observed component - θ_{di}, θ_{ci}, and θ_{yi} and an unobserved one — ε_{di}, ε_{ci}, and ε_{yi}—to control for the possibility that unobservable features of firm organisation and/or the innovation and production decisions lead to co-movements among strategies that are only the result of not having more detailed information about the relevant environment in which firms operate. Note also that there is an independent contribution to profits from other activities of the firm. This separate profit contribution of other strategies also distinguishes between an observed component, $\theta_{\pi i}$, and an unobserved one, $\varepsilon_{\pi i}$. They will be allowed to be correlated with the rest of unobserved returns of the model.

Firms maximise profits by choosing scale and innovation according to their (unobserved) returns to each strategy. We use the envelope theorem to derive the optimal scale decision maximising (1) to obtain an equilibrium profit level conditional on each innovation profile:

$$\pi_i(x_{di},x_{ci}) = \kappa_{\pi i} + \varepsilon_{\pi i} + (\kappa_{di}+\varepsilon_{di})x_{di} + (\kappa_{ci}+\varepsilon_{ci})x_{ci} + \delta_{dc}x_{di}x_{ci} \qquad (22)$$

where the parameters are functions of the observed and unobserved heterogeneity across firms. Estimating this profit function simultaneously with the optimal scale decision and the adoption decisions of product and process innovations (i.e. estimating a system of four simultaneous equations) recognises to the simultaneity of adoption and scale decisions and the fact that all of them affect equilibrium profits. Further, our regressions yield estimates of our complementarity terms in the form of the cross-parameters indicating if the innovation adoption decisions are complements or substitutes, and how they interact with the optimal choice of scale.

IV MEASURING MANAGEMENT PRACTICES AND ORGANISATIONAL STRUCTURE

In the summer of 2006 a team of 51 interviewers ran a management practices survey from the CEP in London on 4,003 firms across Europe, the US and Asia. In this paper we use data on the 1,633 firms from seven European countries (France, Germany, Italy, Poland, Portugal, Sweden and the UK). The management data was collected using the survey tool developed in Bloom and Van Reenen (2007). This survey collects information on 18 questions grouped into four broad areas of management practices, lean techniques, target-setting, monitoring and talent management. Firms are scored from a 1 to 5 basis on each question, with the scores then normalised into z-scores using the complete sample75 so the questions can be aggregated together. The survey uses a double-blind technique to try and obtain unbiased accurate responses to the management 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 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.

Collecting Accurate Responses

An important issue is the extent to which we can obtain unbiased responses to our questions from firms. In particular, will respondents provide accurate responses? As is well known in the survey literature a respondent's answer to survey questions is typically biased by the scoring grid, anchored towards those answers that they expect the interviewer thinks is correct. More generally, a range of background characteristics, potentially correlated with organisational structure may generate some kinds of systematic bias in the survey data. To try to address these issues we took a range of steps to obtain accurate data. First, the survey was conducted by telephone without telling the managers they were being scored on organisational or management practices.[76] 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 used open questions (i.e. "To hire a full-time permanent shop-floor worker what agreement would your plant need from corporate headquarters"?), rather than closed questions (i.e. "Can you hire workers without authority from corporate headquarters?"[yes/no]). Following the initial question the discussion would continue until the interviewer can make an accurate assessment of the firm's typical practices. For example, if the plant manager responded "It is my decision, but I need sign-off from corporate HQ." the interviewer would ask "How often would sign-off typically be given?" with the response "So far it has never been refused" scoring a 4 and the response "Typically agreed in about 80% of the case" scoring a 3. Second, the interviewers did not know anything about the firm's financial information or performance in advance of the interview. This was achieved by selecting medium sized manufacturing firms and by providing only firm names and contact details to the interviewers (but no financial details). Consequently, the survey tool is "double blind" – managers do not know they are being scored and interviewers do not know the performance of the firm. The interviewers were incentivised on the number of interviews they ran and so had no interest in

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[75] The scores are normalised to have a mean of zero and a standard deviation of one across the sample of 4,003 firms.

[76] This survey tool has been passed by Stanford's Human Subjects Committee. The deception involved was deemed acceptable because it is: (i) necessary to get unbiased responses; (ii) minimised to the management practice questions and is temporary (we send managers debriefing packs afterwards); and (iii) presents no risk as the data is confidential.

spending time researching the companies in advance of running the interview. These smaller firms (the median size was 270 employees) would not be known by name and are rarely reported in the business media. The interviewers were specially trained graduate students from top European and U.S. business schools. All interviews were conducted in the manager's native language. Third, each interviewer ran 85 interviews on average, allowing us to remove interviewer fixed effects from all empirical specifications. This helps to address concerns over inconsistent interpretation of categorical responses (see Manski, 2004), standardising the scoring system. Fourth, the survey instrument was targeted at plant managers, who are typically senior enough to have an overview of organisational practices but not so senior as to be detached from day-to-day operations of the enterprise. Fifth, we collected a detailed set of information on the interview process itself (number and type of prior contacts before obtaining the interviews, duration, local time-of-day, date and day-of-the week), on the manager (gender, seniority, nationality, company and job tenure, internal and external employment experience, and location), and on the interviewer (we can include individual interviewer-fixed effects, time-of-day and subjective reliability score). Some of these survey controls are significantly informative about the management practices and are used as "noise controls" to help reduce residual variation.

Ensuring International Comparability

In comparing organisational and management surveys across countries we have to be extremely careful to ensure comparability of responses. To maximise comparability we undertook three steps. First, every interviewer had the same initial three days of interview training, provided jointly by the Centre for Economic Performance and our partnering international consultancy firm. This training included three role-play calibration exercises, where the group would all score a role-played interview and then discuss scoring together of each question. This was aimed at ensuring every interviewer had a common interpretation of the scoring grid. In addition every Friday afternoon throughout the survey period the group met for 90 minutes for training and to discuss any problems with interpretation of the survey. Second, the team operated from one location, the Centre for Economic Performance at the LSE, using two large survey rooms. The different national survey teams were thus listening in on each others surveys on a daily basis, were organised and managed in the same way, and ran the surveys using exactly the same telephone, computer and software technology. Third, the individual interviewers interviewed firms in multiple countries. The team language was English, with every interviewer able to complete English language interviews, so that interviewers were able to interview firms from their own country plus the UK and US. As a result the median number of countries that each interviewer scored was three, enabling us to remove interviewer fixed effects in the cross-country analysis.

Obtaining Interviews with Managers

Each interview took on average fifty minutes and was run in the Summer of 2006. Overall, we obtained a relatively high response rate of 45%, which was achieved through four steps. First, the interview was introduced as "a piece of work"77 without discussion of the firm's financial position or its company accounts, making it relatively uncontroversial for managers to participate. Interviewers did not discuss financials in the interviews, both to maximise the participation of firms and to ensure our interviewers were truly "blind" on the firm's financial position. Second, the survey was ordered to lead with the least controversial questions on (shop-floor operations management), leading on to monitoring, incentives and organisational structure. Third, interviewers' performance was monitored, as was the proportion of interviews achieved, so they were persistent in chasing firms. The questions are also about practices within the firm so any plant managers can respond, with potentially several managers per firm who could be contacted78. Fourth, the written endorsement of many official institutions79 helped demonstrate

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[77] We avoided using the words "research" or "survey" as many firms link these to market research surveys, which they often refuse to be involved with.

[78] We found no significant correlation between the number, type and time-span of contacts before an interview is conducted and the management score. This suggests while different managers may respond differently to the interview proposition this does not appear to be correlated with their responses or the average management practices of the firm.

[79] The Banque de France, Bank of Greece, Bank of Japan, Bank of Portugal, Beijing University, Bundesbank, Confederation of Indian Industry, European Central Bank, European Commission, Greek Employers Federation, IUI

to managers this was an important academic exercise with official support. Fifth, the involvement of Cambridge, LSE and Stanford Universities, along with the institution of the interviewers80, provided a signal of the research focus of the work.

Sampling Frame and Additional Data

Since our aim is to compare across countries we decided to focus on the manufacturing sector where productivity is easier to measure than in the non-manufacturing sector. We also focused on medium sized firms, selecting a sample of firms with predicted employment of between 100 and 5,000 workers (with a median of 270). Very small firms have little publicly available data. Very large firms are likely to be more heterogeneous across plants, and so it would be more difficult to get a picture of organisation in the firm as a whole from one or two plant interviews. We drew a sampling frame from each country to be representative of medium sized manufacturing firms and then randomly chose the order of which firms to contact (see Appendix B for details). Since we use different databases in Europe (Amadeus), the U.S. (Icarus), China and Japan (Oriana) and India (Firstsource) we had concerns regarding the cross-country comparisons so we include country dummies in most of the specifications.

Comparing responding firms with those in the sampling frame, we found no evidence that the responders were systematically different on any of the performance measures to the non-responders. They were also statistically similar on all the other observables in our dataset. The only exception was on size and multinational status, where our firms were slightly larger than average than those in the sampling frame and slightly more likely to be a multinational subsidiary.

V CONSTRUCTION OF AMATECH DATABASE ON FIRM-LEVEL ICT

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 is 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.

Sweden, Ministero delle Finanze, National Bank of Poland, Peoples Bank of China, Polish Treasury, Reserve Bank of India, Shenzhen Development Bank, Sveriges Riksbank, U.K. Treasury and Warsaw Stock Exchange

[80] Interviewers were drawn from the following universities: Berkeley, City of London, Columbia, Harvard, HEC, IESE, Imperial, Insead, Kellogg, LBS, LSE, Lund, MIT, Nova de Lisbon, Oxford, Stanford and Yale.

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.[81] 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[82]. 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. This ownership information represents the raw information used in the analysis of multinational subsidiaries in section III of the report.

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 2008). This process involves standardizing

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[81] HH also refunds data-purchases for any samples with error levels above 5%

[82] 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[83]. Matches can then be assigned a “match quality” according to how close the fit is between company name and firm characteristics is 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 assigns 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 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.

Cleaning and Use of AMATECH Dataset

Practically, the AMATECH dataset needs to be cleaned in both its establishment-level and company-level forms. The cleaning process removes extreme or unusual values or observations from the raw data in order to facilitate accurate estimation. The site or establishment level is cleaned using the following procedures:

- Duplicate observations by site-month-year are dropped from the data.
- Fixed site information is cleaned to establish a standard record. For example, changes in SIC4 industry code are adjusted in cases where they change over time. For example, a site is assigned its most commonly occurring industry code as a “permanent” industry code. The same procedure is followed for variables such as site type and site zipcode.

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[83] For example, all forms of punctuation are stripped out of name strings and company types are abbreviated to short form, ie: “LIMITED” becomes “LTD” and so on.

- The data is cleaned in levels. In particular, we drop all observations with extreme and/or unrealistic values of PCs per person, defined as less 0.05 or greater than 2.
- The site data is then cleaned in changes. Specifically, we winsorize the changes at the 1st and 99th percentiles. That is, in cases where differenced variables are used in regression we top or bottom-code the values to the 1st or 99th percentile.

The site level data is then aggregated to the company-level unit in the AMADEUS database. Specifically, in the case of multi-site firms we add up key variables such as employment, the number of computers and the number of servers as a weighted sum. The site type variables aggregated up as a weighted proportion, that is, the proportion of employees in a HQ or branch site per company. In the instance of fixed variables such as the zipcode or SIC4 industry we assign the company the information that corresponds to the largest site in a multi-site group.

Limitations of the AMATECH Data

A number of practical issues affect the usage of the AMATECH data. These include:

- Subsidiary name-matching: In some countries, vast numbers of similarly subsidiaries complicate the name-matching process. That is, even with cleaned or shortened names there are multiple possible matches for a given site. We have matched these where possible but the algorithm here is imprecise.
- Eastern Europe name matching: Extreme difficulties were encountered with the name matching for Eastern Europe. In particular, very few matches could be made based on automated name matching because of the sheer complication of the languages. The match rates that were achieved were almost solely achieved by manual name matching by research assistants.
- Europe Sampling Problems: There are some changes in sampling policy for the European Harte-Hanks data. In particular, the sample populations for Belgium and the Netherlands turnover in 2000 and 2003 due to a change in sampling design. This severely undermined the construction of panel data for these countries since many surviving firms were not followed up due to the radical change in sample populations.
- US Data: A major problem here is the limited availability of financial accounts data. In the US only large, listed firms need to report their accounts and this limits the scope to create large firm-level panels. Furthermore, it is difficult to compare samples across Europe and the US because of this.

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 (2003)) 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 organisational structures by Bloom, Sadun and Van Reenen(2008)

VI EXISTING LITERATURE ON ECONOMIC IMPACT OF ICT

(i) ICT and Productivity

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). In particular 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.

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 1985). 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. 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.* (2004) 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[84]. 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 (2002) and Van Ark et al (2008) the ICT-intensive sectors are divided between producing and using sub-sectors. A classification is shown in Table B5 with the ICT-using industries defined as those with above-median flows of ICT investment.

The US Productivity Resurgence

An example of a growth accounting exercise that documents the US experience is given in Table B6 (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 B6. Overall growth in output is divided between growth in hours worked and labour productivity

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

(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 is 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 organisational 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 (advanced by Gordon (2003)) and an increase in competitive pressures (Oliner and Sichel 2002).

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 2000a,2000b). 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 ICT 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.

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 but 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 B7). 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 B8. 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. (2004) 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.[85] 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 organisational capital.

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 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 ICT capital over the 1987-2000 period, based on a study of 58 industries (Stiroh 2004). Stiroh's study looked at ICT 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 ICT 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

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[85] Oulton (2003) 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.

example, Basu et al. 2004). 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.

Firm-level Studies

Given concerns about aggregation and other biases attention has shifted to the more micro-level. 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 ICT.

- Second, the magnitude of the IT 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 organisational 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 organisational 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.

- Third, the explanation that the high magnitudes are due to organisational 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[86]. Black and Lynch (2001, 2004) and Caroli and Van Reenen (2001) do not find support for interactions between ICT and organisation, 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 organisational 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 organisation (such as "people management" practices[87]) 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[88]. 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,

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[86] This includes decentralization of control over task allocation and the pace of work to employees and greater teamwork.

[87] This incorporates promotions, hiring and firing and reward systems (see Bloom and Van Reenen, 2007) for a detailed description.

[88] 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.

but also is strongly suggestive of heterogeneity in the ICT coefficient by country, industry, and type of firm.

(iii) Work Life Balance, Job Satisfaction and ICT

The relationship between ICT and employee well-being has been analyzed from different perspectives, such as labor economics, human resource management and information systems management. 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 psychosomatic effects of work life.[89]

Several studies focus on the *process of implementing IT* 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 (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 & Frolick, 2003; Korunka et al., 1995; Korunka & Vitouch, 1999).[90] Giving employees proper ICT training and advice (Chang & Cheung, 2001; Korunka & Vitouch, 1999; Sandblad et al., 2003), as well as enough time to become familiar with the new technology, (Griffith & Northcraft, 1996) also increases job satisfaction.

Conversely, 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 & 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).

ICT is generally considered to have two main effects. On the one hand, it can support and make an employee’s job easier, increasing job satisfaction (Wastell & 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 IT. This may lead to reduced job satisfaction and increased job stress (Edmunds & Morris, 2000) and burnout (Salanova & Schaufeli 2000; Salanova et al., 2000; Salanova et al., 2002). Intuitive examples for both effects are the use of the Internet or electronic mails (Edmunds & Morris, 2000; Kraut & Attewell, 1997; Markus, 1994; Straub & Karahanna, 1998; Teo et al., 1999; Whittaker & 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. The earlier literature focused on the

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[89] We do not consider ergonomics, i.e. ICT’s impact on physical employee well-being.

[90] Of course, it is questionable if this finding is specific to the ICT implementation process or if it is general to implementing technological or organisational innovations in a firm.

use of video display terminals (VDTs) (Steffy & Jones, 1989; Smith, 1987). Ongoing interest looks at the impact of telecommuting on different aspects of well-being with a focus on the social isolation from co-workers (Bailyn, 1989; Cooper & Kurland, 2002; Duxbury et al., 1998; Valcour & Hunter, 2005; Hill et al., 2003; Standen et al., 1999; Wiesenfeld et al., 2001).

Kahn and Cooper (1991) 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) find that enterprise resource planning (ERP) systems have positive impacts on many job characteristics of Hackman and Oldham's (1980) model (see above), and studies on groupware like video conferencing (Agius & Angelides, 1997) and Lotus Notes (Schultze & Vandenbosch, 1998) find similar effects. In a recent study on the working conditions of 2,500 French individuals, Martin et al. (2008) find two types of ICT (computer, internet) positively related to job satisfaction and cell phones having ambivalent effects, increasing some measures of job satisfaction (promotion opportunities, enriching job) while decreasing others (more need to rush, more deadline-quality conflict, more need to handle incidents alone).

Many empirical studies on ICT and work organisation stress that IT induces firms to provide lower-level employees with greater autonomy and install a set of complementary high involvement work practices like screening, training, performance reviews, teambuilding, self-managed teams, and broader jobs (e.g., Brynjolfsson & Hitt, 2000; Bresnahan et al., 2002). These practices have in turn been found to positively influence job satisfaction in a number of studies (e.g. Bauer 2004; Freeman & Kleiner, 2000; Freeman et al., 2000). Also, Autor, Levy, and Murnane (2003) and Spitz-Oener (2006) find a complementary relationship between IT and non-routine analytical and interactive activities, which might increase job satisfaction (Hackman & Oldham, 1980). The main effect of ICT was to replace routine tasks whether they be low skill (e.g. production work on an assembly line) or higher skill (e.g. bank clerks)[91]. Godard (2001) finds that a moderate use of high performance work practices has a positive effect on employee well-being. However, increasing levels of these practices weaken the relationship. 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 linked to harder working conditions (higher risk of work injuries, more mental strain). Other studies find that IT leads to more codified and standardized tasks (Autor, Levy, and Murnane, 2003; Spitz-Oener, 2006) and deskilling (Askenazy and Caroli, 2002), which might decrease job satisfaction (Hackman & 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 the blurring of boundaries between the work and the family life domains allows employees to be more flexible in both domains or if negative spillovers from work to family dominate. Hill et al. (2003) find that IBM telecommuters indeed have more flexibility than traditional office workers to meet both work and family needs. However, they find that this is positive for work life and somewhat negative for aspects of personal life. In interviews, handheld users valued the chance to reach colleagues and being reached more often, but also reported greater challenges to protect personal life. 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.

In summary, the potential effect of ICT use on employee wellbeing and work-life balance in particular is ambiguous. Although the increased mobility awarded by ICT may make it easier to combine work and personal life by, for example, working from home and answering emails on the way to or from the workplace, the pressure of having to be available constantly because the communication technologies in a firm make it possible may have a detrimental effect on an employee's perceived work-life balance and ultimately her satisfaction.

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[91] 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 ICT prices.

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