

Information and Communication Technology use and productivity

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This article presents the main findings from a strand of research aimed at bringing together a range of interdependent metrics on Information and Communications Technology (ICT) use in a single framework, to study the relationship between them, and assess their impact on firm level productivity. This is the first study to bring together such a wide range of IT and CT metrics; one of its intended effects is to put the 'C' into ICT. Analysis has been conducted for major sectors across the UK economy to help policy makers assess which metrics should be targeted for measurement and relative importance in terms of productivity impact.

Introduction

Recent years have witnessed a surge in interest in Information Technology (IT) and its impact on productivity. The initial growth accounting literature, which has consistently found a positive association between IT and productivity, has increasingly been complimented with similar findings from firm-level studies. Due to differences in international survey design, definitions and limited data availability these studies have, however, focused on varying aspects and measures of the new economy.

Maliranta and Rouvinen (2002) have shown productivity effects associated with employee use of computers and the internet for the Finnish economy. In the USA, firm-level studies of computer networks in manufacturing firms have found a positive association between IT and productivity.¹ Similar results are available for manufacturing firms in Japan (Motohashi, 1999, 2002). In the UK Clayton and Goodridge (2002) have looked at e-business use and labour productivity; their results are supported by evidence on productivity and pricing effects of ecommerce. More recently, Bloom, Sadun and Van Reenen (2005) find productivity effects associated with IT investment using UK business returns from investment surveys.

We bring together these measures under one framework to assess the impact of each on different business models across different sectors. There are clearly linkages between the different metrics; IT investment supports IT enabled employees and computer networks and telecoms use is necessary to equip the workforce with Internet and e-commerce. But, it is important to consider what these individual components are measuring and why any analysis on ICT impact should include one or more of these measures.

Hardware capital stock, will include expenditure on network servers and computers etc. but also contains expenditure on operating platforms and other application-specific software programs that are built into the hardware. It therefore represents fixed investment in IT infrastructure and to some extent encapsulates all the other IT measures.

Software capital will capture both purchased software, consisting of packaged application-specific and non-application programs but mostly purchases of customised software, and to a small extent expenditure on software produced in-house for use within the firm. In both cases software capital embodies extensions and changes to the basic IT infrastructure specific to the firm-systems re-engineering that leads to improved efficiency and productivity.

'Employees using ICT', as a measure, is likely to embody human capital, work organisation and structure and management attitude towards knowledge-sharing. Whereas, telecommunications service use provides a general proxy for external relationships, e-commerce provides a more specific measure of commercial infrastructure.

Reported below are the main findings for the manufacturing and service sectors. A more detailed exposition of the analysis and results for individual service sectors can be found in *IT use by firms and employees: Productivity evidence across industries*, Office for National Statistics (ONS) research paper series.

Data

Financial information at firm level is gathered through the Annual Business Inquiry (ABI). This survey provides information on employment, gross output, turnover and material inputs, including spend on telecommunication services and firm characteristics such as ownership status and whether the firm is part of a bigger enterprise group. The Investment section of the ABI is used to construct our non-IT capital stock. Since 2000 the ABI includes a section on e-commerce which we use to identify firms that trade electronically.

The E-commerce Inquiry, begun in 2000, is an annual survey dedicated to collecting data on ICT use. Since 2001 it has collected data on the proportion of the labour force equipped with ICT. Both surveys population-sample the largest firms and run a stratified sample on small and medium sized enterprises. Matching information from the two sources provides a valuable link between ICT use and productivity. The E-commerce survey can also be used to provide more detailed information on the nature of electronic trade: distinguishing between types of product sold and the medium of trade, but the ABI provides a larger sample size and is our choice survey on e-commerce information.

The IT capital stock is constructed from expenditure returns of surveyed firms. Details of construction methodology can be found in Bloom *et al* (2005). Although, our dataset runs from 2000 to 2003, most of the information relates to the years 2001 to 2003.

Table D1

Firm characteristics in manufacturing by type of trade decision, 2002

Percentages (relative to SIC4 digit industry mean)

		Employment	Value Added per employee	Gross Output per employee	Capital per employee	Telecom spend per employee	Hardware per employee	Software per employee	Share of employees with access to computer	Share of employees with access to Internet
e-buy	Mean	109	103	102	104	102	109	105	110	109
	Std Deviation	105	43	50	67	61	109	124	44	66
	Observations (no-s)	765	765	765	765	765	765	765	145	145
e-sell	Mean	105	100	101	100	100	100	102	102	103
	Std Deviation	93	43	50	64	59	98	121	50	68
	Observations (no-s)	942	942	942	942	942	942	942	196	196
None	Mean	89	98	99	98	99	95	93	92	89
	Std Deviation	76	40	43	59	54	112	114	39	57
	Observations (no-s)	570	570	570	570	570	570	570	74	74

Table D2

Firm characteristics in services by type of trade decision, 2002

Percentages (relative to SIC4 digit industry mean)

		employment	Value Added per employee	Gross Output per employee	Capital per employee	Telecom spend per employee	Hardware per employee	Software per employee	Share of employees with access to computer	Share of employees with access to Internet
e-buy	Mean	121	103	104	105	104	109	106	101	104
	Std Deviation	221	60	73	100	84	128	149	58	80
	Observations (no-s)	1,283	1,283	1,283	1,283	1,283	1,283	1,283	334	334
e-sell	Mean	115	101	102	103	100	107	102	106	112
	Std Deviation	218	60	68	93	75	118	129	66	94
	Observations (no-s)	1,057	1,057	1,057	1,057	1,057	1,057	1,057	307	307
None	Mean	81	98	97	96	97	92	94	94	89
	Std Deviation	131	62	71	111	79	109	132	80	103
	Observations (no-s)	1,150	1,150	1,150	1,150	1,150	1,150	1,150	256	256

A sizeable proportion of our sample trade electronically: approximately 45 per cent of businesses run electronic procurement systems and 44 per cent of businesses receive orders via an electronic medium. Tables D1–D2 present descriptive statistics for our sample of manufacturing and service sector firms based on their decision to trade over electronic platforms. Variables are expressed as deviations from their four digit industry means.

Unsurprisingly, the decision to trade electronically is accompanied by higher than average spend on telecommunications and IT infrastructure. E-traders also have a higher share of ICT-equipped employees. Characteristics vary by sector: in manufacturing, firms with e-procurement systems are more capital intensive, spend up to 2 per cent more than the industry average on telecoms, 8 per cent more on hardware capital and have 10 per cent more ICT-equipped employees.

In services e-buyers are again the bigger spenders on IT and CT, but e-sellers employ a higher share of ICT equipped labour. In 2002, the Internet-equipped labour share for e-sellers was 11 per cent higher than the industry average.

In nearly all sectors it is the firms with e-procurement systems in place that are the most productive. In terms of value-added per worker e-sellers are more productive than the industry average, however this difference is minimal. Retail is the only sector where firms with electronic links to customers enjoy higher labour productivity than e-procurers.² Overall, the gains to electronic trade are not very large compared to industry averages and, more importantly, to firms without electronic trading platforms.

The descriptive statistics (not presented here)³ also indicate that there is a degree of experimentation in younger firms. Regardless of the sector we look at, young firms are generally more capital-intensive. They spend more than the industry average on IT investment and CT and have higher ICT-equipped labour share, however, this does not necessarily translate into much higher value added per employee compared to older firms.

Figures 1 and 2 show the relationship between the ICT equipped labour share and labour productivity. The figures reported are unweighted sample averages but the message is clear: the most productive firms are those that employ a high share of labour with frequent access to ICT. Of course, there are likely to be a multitude of factors driving this representation. A high ICT equipped labour share may reflect a high skill intake, or indeed work organisation and management practices that are conducive to a productive environment. We tackle these issues in the following sections.

Econometric strategy

The modelling strategy laid out in Bloom *et al* (2005) forms the basis of our estimation technique. We assume that firm *i* faces a generalised Cobb–Douglas production function $Q_{it} = A_{it} F_i(X_{it})$, where Q is the output of firm *i*, $F(X)$ is the part of the production that is common to all firms within an

Figure 1
ICT equipped labour share and labour productivity in manufacturing

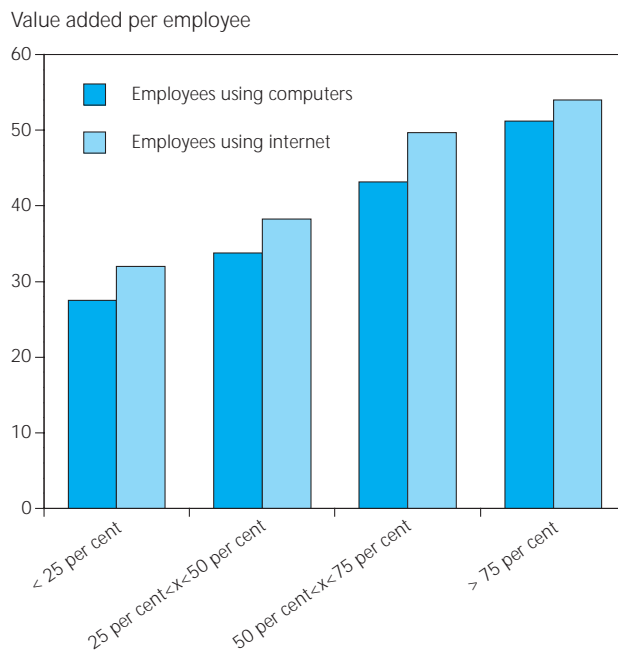
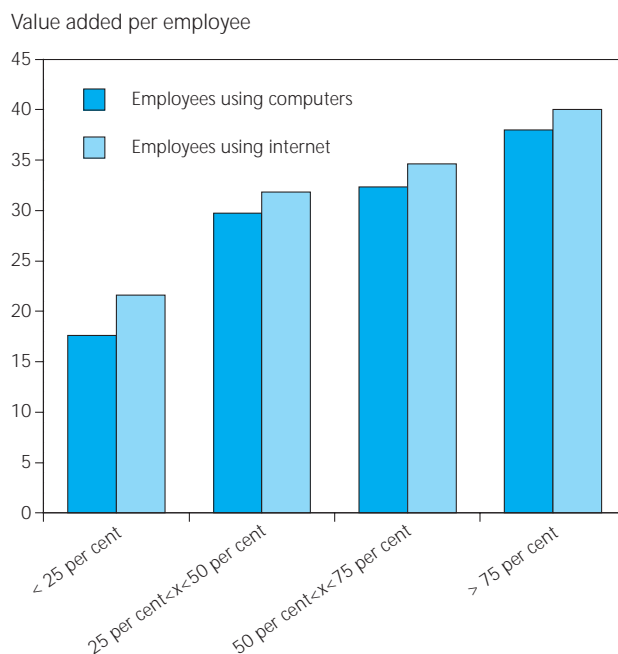


Figure 2
ICT equipped labour share and labour productivity in services



industry and A refers to firm-specific efficiency not related to the input factors. X_{it} includes factor inputs such as capital and labour.

Using a logarithmic transformation we can rewrite our production function as:⁴

$$q_{it} = \alpha_{it} + \alpha_{it}^{NIT} k_{it} + \alpha_{it}^H h w_{it} + \alpha_{it}^S s w_{it} + \theta_{Lit} (l_{it} / l_{it}^*) + (\alpha_{it}^{NIT} + \alpha_{it}^H + \alpha_{it}^S + \beta_L - 1) l$$

where q is a measure of output per employee, k is non-IT capital per employee, l is labour input and hw (hardware) and sw (software) denote our measures of IT capital per employee.

As in Maliranta and Rouvinen (2002) we assume that all workers are perfect substitutes, however, we allow these workers to have different marginal productivities depending on whether they use ICT (l_{ict}) or not (l_o).

Lehr and Lichtenberg (1999) propose improvements in communication as likely to improve overall efficiency in production and lead to proportionate increases in productivity across all factors. We are particularly interested in specific forms of communication that are captured in computer networks. We consider representing total factor productivity in the following way:

$$a_{it} = \alpha_i + \alpha_1 t + \alpha_2 etrade + \gamma z_{it} + u_{j,it}$$

where t represents a firm's rental payment on telecommunications and $etrade$ is a dummy variable that identifies firms using computer networks to trade electronically. Criscuolo and Waldron (2003) find productivity impacts vary with type of trade. We therefore distinguish between selling and buying over electronic networks. Other observable factors such as multinational ownership, regional location and affiliation to multi-plant groups are captured in z . The equation to be estimated can then be written as:

$$q_{it} = \alpha_i + \alpha_1 t + \alpha_2 etrade + \alpha_{it}^{NT} k_{it} + \delta_{it}^H hw_{it} + \delta_{it}^S sw_{it} + \theta_{ict} (l_{ict,it} / l_{it}) + (\sum \alpha_{it}^{NT} + \beta_L - 1) l + \gamma z_{it} + u_{j,it}$$

Our estimation technique relies on Least Squares regressions that are fully robust to a generalised heteroskedastic error term structure that allows for serial dependence over time. It is likely that our results will be affected by unobserved factors such as management practices. Fixed effects would help to control for such time-invariant factors, however the reliability of results is hampered by measurement error.⁵ In order to facilitate international comparison, we use value added as measure of output. This also has the additional advantage of allowing us to discern the pricing impacts that are an inherent part of electronic trade.

We analyse the impact of all the ICT variables mentioned above, but the results here focus on the impact of employee use of ICT and telecommunications. Results relating to IT investment and e-commerce are briefly mentioned and interested readers can find the accompanying tables and explanations in the long version *IT use by firms and employees: Productivity evidence across industries*, ONS research paper series.

Results

IT investment

Tables 1 and 2 report regression outputs for manufacturing and services. The first column, in each table, shows the impact of IT investment when modelled on its own. Across all specifications, both our measures of IT capital are positive and significant. In manufacturing, the elasticity of hardware with respect to productivity is 5.6 per cent. In services it is markedly higher at 8.1 per cent.⁶ The impact of software is slightly lower than of hardware in both manufacturing and services. This is likely to be due to a higher degree of measurement error associated with software. The coefficients on the IT measures are systematically higher for services.

Employee use of ICT

In their study Maliranta and Rouvinen (2002) identify the computer and Internet equipped labour share as proxies for IT investment. By capturing the degree of involvement of the workforce with ICT these measures also act as indicators of work organisation and skills. In practice these metrics are also likely to measure the electronic exchange of information between employees – and with outside sources – so may give an imperfect measure of networking and knowledge management currently available at firm level.

The data on employees using computers and the Internet is, not surprisingly, correlated with IT investment at firm level. It is also strongly dependent on industry sector. However, the identifiable effects of employee computer / Internet use on firm level productivity are large and significant.

The second column in each table, shows results on employees using computers. In addition to the impact of IT investment, employee use of computers has a positive impact on firm productivity. In manufacturing, use of computers by the workforce raises productivity by 2.1 per cent for every additional 10 per cent of employees IT-enabled.

For services we also find an additional impact of employee use over and above that accounted for by IT investment. Partly because of the higher impact of investment, and partly due to diminishing returns the impact is slightly lower, with increases of 1.5 per cent for every 10 per cent enabled.

The use of the Internet by the workforce has a positive impact on productivity above that explained by IT investment (Column 3, Tables 1 and 2). In manufacturing, enabling staff with the Internet raises productivity by 2.9 per cent for every 10 per cent enabled. Unlike manufacturing we do not find significant differences in impact between Internet and computer use in services.

Table 1
ICT use in manufacturing

	(1)	(2)	(3)	(4)	(5)
Dependent variable	ln(VA/EMP)	ln(VA/EMP)	ln(VA/EMP)	ln(VA/EMP)	ln(VA/EMP)
Log of non-IT capital per employee	0.223*** (0.013)	0.256*** (0.029)	0.257*** (0.029)	0.207*** (0.014)	0.221*** (0.028)
Log of employee	0.032*** (0.010)	0.043* (0.023)	0.043* (0.023)	0.044*** (0.010)	0.068*** (0.023)
Log of hardware per employee	0.056*** (0.007)	0.038** (0.015)	0.037** (0.015)	0.012 (0.020)	-0.019 (0.043)
Log of software per employee	0.041*** (0.006)	0.032** (0.013)	0.031** (0.013)	0.038*** (0.006)	0.034*** (0.013)
Computer equipped labour share		0.215*** (0.064)			
Internet equipped labour share			0.295*** (0.073)		0.239*** (0.073)
Log of telecom spend per employee				0.075*** (0.013)	0.093*** (0.026)
Hardware*telecom spend				0.009** (0.005)	0.011 (0.009)
Skills					
Proportion of people with a college degree in industry-region cell		0.235 (0.262)	0.300 (0.261)		
Observations	5,397	1,317	1,317	5,397	1,394
R-squared	0.46	0.64	0.65	0.47	0.64

Robust standard errors in parentheses

* significant at 10 per cent; ** significant at 5 per cent; *** significant at 1 per cent.

The dependent variable in all columns is the log of value added per employee (measured in £'000s). Non-IT capital, IT capital and Telecom spend are all measured per employee in £'000s and expressed in logs in the regression. The time period is 2000–2003. Standard errors in brackets under coefficients are clustered by establishment and robust to heteroskedasticity and serial autocorrelation. All variables are expressed in deviations from the 4digit Industry mean in the same year. Telecom Spend per employee is measured in nominal terms. All regressions include age, region, ownership and group dummies.

It can be argued that the employee use measure is simply acting as a surrogate for skills. Indeed there is a growing literature on the complementary relationship between IT investment and use and skills. To account for the skills effect we have included a skills measure in regression specifications based on regional educational attainment levels available to the SIC 2-digit industry. The results are robust and suggest employee use of ICT is – as an indicator – far more than a proxy for IT investment.

Telecommunications spend

Communications technology equipment input is, for most firms outside the communications sector, dominated by purchase of external infrastructure services. Less than 15 per cent of investment in telecommunications products is made by firms outside the communications sector for their own use.⁷ Because most firms use external telecommunications infrastructure – purchased from outside service suppliers – it is difficult to reflect the contribution made by the ‘Communications’ element of ICT in the same way as we

have for IT. So the best measure of telecommunications use by firms is their external spend on purchased services. We use telecom spend per employee, identified through the ABI, as an indicator of communications infrastructure.

Telecoms use has a large positive and significant effect on firm output across manufacturing and services. It explains up to 7.5 per cent of productivity differences in manufacturing firms—after accounting for the effects of IT capital (Column 4, Table 1). Within manufacturing it also reinforces the productivity effects associated with hardware investment (Column 4 interaction between hardware and telecom spend).

Similar results hold for the service sector (Column 4, Table 2). The impact of telecom use does vary across the service sectors. It appears to be greatest in distribution services where the IT–CT interaction replaces hardware investment as the main productivity influence. This suggests that the role of IT in co-ordinating and managing complex supply chains and external links is much more critical than as a driver of internal efficiency.

Table 2
ICT use in services

	(1)	(2)	(3)	(4)	(5)
Dependent variable	ln(VA/EMP)	ln(VA/EMP)	ln(VA/EMP)	ln(VA/EMP)	ln(VA/EMP)
Log of non-IT capital per employee	0.268*** (0.012)	0.274*** (0.025)	0.264*** (0.025)	0.245*** (0.012)	0.249*** (0.025)
Log of employee	-0.047*** (0.007)	-0.021*** (0.015)	-0.060*** (0.015)	-0.055*** (0.008)	-0.011 (0.016)
Log of hardware per employee	0.081*** (0.007)	0.097*** (0.014)	0.095*** (0.014)	0.032** (0.016)	0.094** (0.039)
Log of software per employee	0.055*** (0.006)	0.046*** (0.012)	0.044*** (0.012)	0.053*** (0.006)	0.037*** (0.012)
Computer equipped labour share		0.022 (0.053)			
Internet equipped labour share			0.154*** (0.056)		0.128** (0.055)
Log of telecom spend per employee				0.074*** (0.013)	0.064*** (0.022)
Hardware*telecom spend				0.010*** (0.003)	-0.001 (0.007)
Skills					
Proportion of people with a college degree in industry-region cell		0.206 (0.420)	0.158 (0.419)		
Observations	8,255	2,231	2,231	8,255	2,272
R-squared	0.60	0.70	0.71	0.60	0.70

Robust standard errors in parentheses.

* significant at 10 per cent; ** significant at 5 per cent; *** significant at 1 per cent.

The dependent variable in all columns is the log of value added per employee (measured in £ 000s). Non-IT capital, IT capital and Telecom spend are all measured per employee in £ 000s and expressed in logs in the regression. The time period is 2000–2003. Standard errors in brackets under coefficients are clustered by establishment and robust to heteroskedasticity and serial autocorrelation. All variables are expressed in deviations from the 4digit industry mean in the same year. Telecom Spend per employee is measured in nominal terms. All regressions include age, region, ownership and group dummies.

Column 5 in Tables 1 and 2 presents the impact of employees using the Internet alongside telecommunication spend.

Note that the interaction between hardware and telecom spend becomes insignificant and the effects of hardware also disappear (supporting our hypothesis that the employee use measure is a good indicator of networking within firms).

However, effects of software and telecoms use remain strong and significant, suggesting that systems, communication and the effective use of both IT and CT is decisive to productivity in both manufacturing and services.

E-commerce

Work by Criscuolo and Waldron (2003) demonstrated, using UK data, that manufacturing firms which use e-commerce showed value added productivity gains associated with electronic buying and smaller productivity losses associated with electronic selling. Together with evidence showing a tendency for prices to decline among firms selling electronically compared to those which do not, this was interpreted to show an overall efficiency gain

associated with electronic process use and market price effects in favour of electronic buyers, through stronger price competition. This study extends their analysis in two ways: firstly we model the effects of ecommerce alongside our other measures of ICT use, and we also extend the analysis of e-commerce to the service sector.

Our results corroborate the existing findings in the literature. In commodity markets such as manufacturing, e-selling negatively impacts on value added productivity resulting from added price pressures. Manufacturing firms gain from e-procurement and the net effect of e-trade is to raise productivity by 1–2 per cent. The impact of e-trade in services is more complex and varies between detailed sectors. Distribution services, however, exhibit gains from e-selling of around 4 per cent.

Age of firm

To assess whether the impact of IT varies within sectors we split our sector samples by the age of the firm. Firms are categorised as young and old in relation to their four digit

Table 3
IT capital and use by age of firm in manufacturing

	(1)	(2)	(3)	(4)	(5)	(6)
Dependent variable	ln(VA/EMP)	ln(VA/EMP)	ln(VA/EMP)	ln(VA/EMP)	ln(VA/EMP)	ln(VA/EMP)
Sample	Young firms	Young firms	Young firms	Old firms	Old firms	Old firms
Log of non-IT capital per employee	0.192*** (0.022)	0.183*** (0.053)	0.207*** (0.052)	0.263*** (0.018)	0.339*** (0.043)	0.329*** (0.043)
Log of employee	0.006 (0.016)	0.020 (0.048)	0.018 (0.046)	0.052*** (0.014)	0.056 (0.035)	0.051 (0.034)
Log of hardware per employee	0.063*** (0.012)	0.002 (0.028)	0.014 (0.030)	0.047*** (0.008)	0.067*** (0.020)	0.062*** (0.020)
Log of software per employee	0.045*** (0.011)	0.050* (0.029)	0.049* (0.029)	0.032*** (0.008)	0.018 (0.018)	0.016 (0.018)
Computer equipped labour share		0.438*** (0.123)			0.093 (0.084)	
Internet equipped labour share			0.337** (0.139)			0.259** (0.108)
Skills						
Proportion of people with a college degree in industry-region cell	0.027 (0.234)	-0.201 (0.735)	-0.332 (0.732)	-0.111 (0.167)	0.331 (0.334)	0.469 (0.319)
Observations	2,026	526	526	3,160	791	791
R-squared	0.53	0.78	0.77	0.55	0.72	0.73

Robust standard errors in parentheses.

* significant at 10 per cent; ** significant at 5 per cent; *** significant at 1 per cent.

The dependent variable in all columns is the log of value added per employee (measured in £ 000s). Non-IT capital, IT capital and Telecom spend are all measured per employee in £ 000s and expressed in logs in the regression. The time period is 2000–2003. Standard errors in brackets under coefficients are clustered by establishment and robust to heteroskedasticity and serial autocorrelation. The age of a firm is determined by median age in its four digit sector. All variables are expressed in deviations from the 4 digit industry mean in the same year. All regressions include age, region, ownership and group dummies. Young firms are differentiated from old firms by median age in 4 digit industry.

Table 4
IT capital and use by age of firm in services

	(1)	(2)	(3)	(4)	(5)	(6)
Dependent variable	ln(VA/EMP)	ln(VA/EMP)	ln(VA/EMP)	ln(VA/EMP)	ln(VA/EMP)	ln(VA/EMP)
Sample	Young firms	Young firms	Young firms	Old firms	Old firms	Old firms
Log of non-IT capital per employee	0.302*** (0.016)	0.342*** (0.035)	0.337*** (0.035)	0.253*** (0.014)	0.216*** (0.030)	0.209*** (0.030)
Log of employee	-0.026*** (0.010)	-0.063*** (0.021)	-0.061*** (0.021)	-0.032*** (0.009)	-0.038** (0.019)	-0.035* (0.019)
Log of hardware per employee	0.060*** (0.009)	0.082*** (0.020)	0.080*** (0.020)	0.083*** (0.008)	0.111*** (0.016)	0.110*** (0.016)
Log of software per employee	0.058*** (0.009)	0.048*** (0.019)	0.048*** (0.019)	0.056*** (0.007)	0.039*** (0.013)	0.038*** (0.013)
Computer equipped labour share		0.019 (0.084)			0.020 (0.066)	
Internet equipped labour share			0.168** (0.083)			0.110 (0.067)
Skills						
Proportion of people with a college degree in industry-region cell	0.367 (0.336)	0.447 (0.709)	0.421 (0.703)	-0.196 (0.237)	-0.138 (0.434)	-0.185 (0.430)
Observations	3,588	960	960	4,552	1,271	1,271
R-squared	0.71	0.81	0.81	0.68	0.74	0.75

Robust standard errors in parentheses.

* significant at 10 per cent; ** significant at 5 per cent; *** significant at 1 per cent.

The dependent variable in all columns is the log of value added per employee (measured in £ 000s). Non-IT capital, IT capital and Telecom spend are all measured per employee in £ 000s and expressed in logs in the regression. The time period is 2000–2003. Standard errors in brackets under coefficients are clustered by establishment and robust to heteroskedasticity and serial autocorrelation. The age of a firm is determined by median age in its four digit sector. All variables are expressed in deviations from the 4 digit industry mean in the same year. All regressions include age, region, ownership and group dummies. Young firms are differentiated from old firms by median age in 4 digit industry.

industry median age. This specific categorisation allows the cohort of middle-aged firms to transition from young, at the beginning of our sample period, to old in later years. Results for manufacturing and services are presented in Tables 3 and 4.

For young manufacturing firms the total impact of IT investment, that is hardware and software capital, is as high as 12 per cent, significantly higher than the 8 per cent for older firms. In young firms the productivity effects of equipping employees with computers are more statistically significant (and bigger in terms of impact) than productivity effects associated with the level of IT investment. For each 10 per cent of the workforce, computer-enabled young firms see a return of 4.4 per cent. This mirrors the findings on IT investment but also suggests that employee use of ICT is a particularly valuable metric for younger firms entering manufacturing sectors.

The losses in value-added associated with e-selling in manufacturing are primarily driven by losses incurred by younger firms. Although older firms do not seem to show any gains from e-selling they do not experience significant losses either. E-procurement is just as beneficial for older firms as for the young and accounts for up to 5 per cent of the productivity difference between firms that trade electronically and those that do not.

In services, benefits from IT investment take longer to manifest as explained by the higher coefficient on hardware for older firms, however, employee access to the Internet is strongly significant for young firms. It is also in e-selling where older firms show an advantage and see gains of nearly 4 per cent. Similar dynamics are apparent in retailing where again the positive gains from e-selling, which are as high as 6 per cent, accrue primarily to older established firms.

The age effects of IT may reflect different competitive dynamics in manufacturing and services. Manufacturing firms are more likely to use IT to optimise value chains and operations, which can change quickly and require a certain degree of flexibility. Younger firms are generally more flexible, which facilitates adoption and implementation of newer technologies⁸, allowing them to experiment more. Benefits from access to wider supply sources and reduced search costs which e-procurement brings are also larger for younger firms. The case for flexibility is strong in manufacturing; however, we also see a degree of learning. The impact of e-selling which is strong for young manufacturing firms but is not visible for older businesses suggest that this negative effect disappears as firms undertaking e-selling overcome initial set up costs, gain scale and learn how to operate the process more effectively.

In services, productivity gains stem from learning rather than flexibility. The gains from IT investment accrue to older firms that learn to use the technology to simplify the information needs associated with dealing with large numbers of end users. The key to services lies in building up client knowledge bases and customer relations, and once initial set up costs are overcome, gains are likely to come from channeling improved supply chain models and inventory management, especially in distribution services. This is reflected in a larger coefficient on

hardware capital for older firms compared to younger firms, but is more pronounced when we look at e-commerce, with the gains from e-selling primarily accruing to older firms.

In young service firms Internet-equipped labour share raises productivity by 1.7 per cent for each 10 per cent enabled and it does so without affecting the relationship between IT investment and productivity. A similar effect for computers is absent. This shows that the skills, communication links and organisation measured by use of the Internet have a specific and identifiable role for young service firms.

Conclusion

We bring together three different measures of IT use, and for the first time, explicitly model the effects of communications. Using our panel and Least Squares estimation techniques, we assess the relationship between these interdependent measures and their impact on productivity in the UK economy for years 2000 to 2004. The study looks at differences across sectors and within sectors by analysing the age of the firm.

Our results show differences in impact of IT investment across sectors, with the strongest gains in the services industry. In manufacturing, we find that younger firms are able to get more out of their IT investment than older firms. In young manufacturing firms, enabling employees with computers and Internet is a more significant driver of productivity than investment on its own.

In contrast, we find a degree of learning involved in the service sector where IT capital and networks are primarily used to build up client and service provision knowledge bases. This is strongly manifest in the e-commerce results for distribution services: established firms see positive gains in value added from e-selling.

For the first time we look at spending on telecommunication services as a possible driver of productivity and find a strong relationship between the two. We also find a strong association between IT investment and CT spend, with increased spending on the latter compounding the effects of IT investment.

Future work will involve improving our measure of communication infrastructure and looking at the adoption, usage and impact of broadband technologies. We also plan to build and implement improved measures of skills to look at complementarities between skills and ICT investment and use and resolve endogeneity concerns.

Notes

1. Atrostic and Nguyen (2002, 2004) incorporate a dummy computer network and business processes into standard production function approach and find positive impacts on productivity.
2. See long version for descriptive statistics and regression results for distribution (wholesale and retail) services *IT use by firms and employees: Productivity evidence across industries*, available at www.statistics.gov.uk/cci/article.asp?ID=1233
3. Available in long version.

4. Lowercase denotes the logarithmic transformation, that is, $\ln(X) = x$
5. Griliches and Mairesse (1997) present a general discussion of this problem with production functions and see Brynjolfsson and Hitt (1995, 1996, 2003) for an argument that is particularly relevant to ICTs.
6. See the accompanying *Economic Trends* article R Sadun, 'The role of IT in Firm Productivity' for other elasticity estimation techniques and results.
7. ONS Supply-Use Table 2002.
8. See Christensen and Rosenbloom (1995) for a detailed exposition.

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