ICT impact assessment by linking data

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Summary

During 2006-2008 13 EU statistics offices, and academic contributors, carried out a research project

- to develop new indicators on the economic impact of ICT in business with existing surveys and
- to extend consistent analysis of ICT impacts to new countries.

The analysis develops data linking across surveys, including, for all 13 countries, the common EU ICT use enterprise survey, the Structural Business Survey and business register and, for some countries, surveys in skills, international sourcing, ICT investment and innovation. It covers over 200,000 firms.

From evidence on ICT - productivity links in single country studies using firm level data, the study identifies core metrics which all countries can analyse, plus 'lead' analyses in groups of countries with additional data available. Analysis focuses on indicators related to productivity and growth impacts.

The study begins by focusing on firm level analysis, and then develops an industry based analysis method, using comprehensive metadata, used to produce ICT, and other, indicators on a strictly comparable basis across industries and countries. This allows technology use data to be combined with other economic data in productivity and growth analysis, including EU KLEMS.

The results show productivity effects associated with ICT through competitive substitution over and above 'within firm' effects. Firm level analysis in Sweden and Netherlands suggests that part of the productivity impact of ICT is associated with its effect as a facilitator of wider innovation.

This paper compares the results of the study with recent work in the US, and macroeconomic measurement work on ICT and complementary investment in a number of OECD countries. It concludes by outlining objectives for the next round of research in this area.

Acknowledgements

This project included over 30 researchers from CSO Ireland, Czech Statistical Office, INSEE, ISTAT, German Federal Statistics Office, UK Office for National Statistics, Statistics Austria, Statistics Denmark, Statistics Finland & The Research Institute of the Finnish Economy, Statistics Netherlands, Statistics Norway, Statistics Sweden, Vrije Universiteit Amsterdam, University of Ljubljana, Queen Mary University of London and London School of Economics

We thank all who have supported and contributed to this project, esecially Prof Eric Bartelsman of VUA and the Information Society team at Eurostat. Any errors are the responsibility of the authors.

The full study report (Eurostat 2008) was published in November 2008 by the European Commission on its website at http://ec.europa.eu/eurostat/ict, under the heading 'Methodology'

1. Introduction and Background

1.1. ICT indicator development for policy

Information Society indicators have a short history in the European Statistical System. Nordic countries, and INSEE, took a significant interest in how information and communication technology (ICT) was being used in industry, and in society, in the mid 1990s, as the use of networks began to impact on more firms and households. .

After OECD's 1998 ministerial meeting on e-commerce, member states set out to develop common statistical approaches to measuring the information society, at work, in the home and in the wider community. Initial conceptual work on definition of the ICT industries and of ICT products and services, on e-commerce and measurement of ICT use in business and households was led by a small group of countries, including Canada and Australia..

The approach used to develop metrics focused on understanding the transformation of economic and social relationships by ICTs. A linear model was used, aimed at understanding:

- 'readiness' of economies and institutions, businesses, households and government, to accept or perform electronic transactions of various kinds,
- 'use' of ICT, e-commerce and electronic business processes, and
- 'impact' or change in behaviour and performance of economic and social actors

This 'S curve' approach dominated early years of statistical development. It accompanied policy focus on building the foundations for internet use, through education, familiarisation, infrastructure in terms of equipment and the creation of networks. There was little empirical evidence on gains from the 'impact' of ICT. It was assumed that economic and social benefits of ICT would become evident, and that Solow's Paradox of 1989 "You can see the computer age everywhere but in the productivity statistics" (Solow R M. 1987) would be resolved. This resolution took over a decade.

ICT measurement in the EU was given impetus in 2001 by adoption of the Lisbon strategy to promote Europe as a 'dynamic knowledge based economy'. The Council of Ministers committed to policies through which innovation, including development of ICT use, would break the EU's poor productivity performance compared to the US. A set of policy indicators was created to monitor progress.

Indicators for innovation in the EU's Structural Indicators include ICT investment and e-commerce use. ICT investment is measured by private sector sources, as national accounts estimates were not considered reliable. Consistent measures of use of electronic transactions use official surveys, on business use of computers, networks, internet and e-commerce to more complex questions on e-business processes, barriers and benefits of use, employee engagement, security, and skills.

Eurostat developed a range of indicators specifically to monitor the 'e-Europe' programme from 2001 to 2005. Most were designed to measure the 'e-readiness' and 'use' stages of ICT development in households, government and business. Attention focused on individual / household measures of IT and internet use, on education and government services, with the largest section on business metrics.

1.2. ICT macro impact analysis

Early assessments of the economic impact of ICT on an international scale were largely based on macro economic analysis. An OECD review as late as 2003 concluded that 'evidence on the role of ICT investment is primarily available at the macroeconomic level'. This was aided by the 1993 decision to treat software investment as an asset in the System of National Accounts (SNA), which allowed analysis of the role of ICT investment (hardware and software) in growth accounting across the majority of developed economies.

Comparisons by OECD (OECD 2004) show, for the 1990s, how ICT investment contributed to overall growth across 15 member states, and split out the productivity effects for ICT producing industries, and for ICT using manufacturing and for ICT using services. The study highlights strong ICT investment in service industries – but much early impact analysis focused on manufacturing for measurement reasons. While it showed ICT investment contributing to growth and productivity, differences between countries were striking.

Strong multi-factor productivity growth in the US associated in this study with ICT use was interpreted as a result of the US' early lead in adoption of ICTs, overcoming adjustment costs and benefiting from competitive markets in which entry, exit and adjustment were easier. For a number of EU economies the contribution of ICT use to productivity growth did not grow.

A major difficulty in early assessments of ICT impacts for policymakers was that estimates of ICT investment in macro-economic data were not consistent across countries. Macro estimates through the late 1990s were also complicated by the 'dot com boom' which changed market conditions to such an extent that productivity gains were attributed to this rather than to structural or technological change. Productivity gains could be seen in the (fast growing) ICT producing industries, but benefits for ICT users were less clear.

Industry analysis is the focus of more recent work in the US. Brynjolfsson and colleagues, in 'Scale without Mass' (Brynjolfsson et al, 2006) looked at the relationships between industry ICT intensity, and the characteristics of competition across US industries and concluded that:

- greater ICT use speeds up experimentation and diffusion of new, successful, business models by 'winning' firms, and is associated with more market share change in industries;
- the effect of this process is to encourage increasing supply concentration, as successful firms supported by ICT grow, and others lose market share or exit the market.

This US analysis draws no specific empirical conclusions on productivity or on economic performance associated with technology. However the 'KLEMS' initiative starting in 2004 and funded by the EU was designed to take industry level National Accounts data and develop growth accounting models by industry taking account of capital (K), labour (L), energy (E), materials (M) and services (S). Among inputs identified as part of this programme is ICT capital (as part of K).

KLEMS results show significant differences across countries, and between the EU and the US, in the growth accounting impact of ICT investment. The broad picture demonstrates that: differential gains in productivity in more intensive ICT using industries have been an important part of the US productivity advantage over the decade to 2004, and that distribution and business / financial services show the most substantial gains.

The data shows these differences largely in terms of TFP (i.e. unexplained) growth. This suggests that National Accounts data on ICT investment may not be sufficiently well developed to act as a good explanatory variable – essentially the same conclusion as that reached by the compilers of the EU structural indicators.

ICT investment measurement is explored in work by the UK Office for National Statistics (Chamberlin et al 2006). As the proportion of IT investment is increasingly weighted towards software rather than hardware, and the proportion of software created outside the IT industry grows, official IT investment estimates require more assumptions

An additional factor which affects the pattern of ICT investment, revealed by this project, is the growing importance of IT service outsourcing. Finnish analysis, using survey questions on outsourcing of IT services, shows that productivity incentives for outsourcing IT are strongly positive. This may influence the distribution of IT investment across industries, and make it unrepresentative of the pattern of ICT use, and so of the impact of ICT on business operations. Direct measures of ICT use may be a better way of assessing this.

1.3. Firm level impact analysis

By 2002/3 extensive experience had been gained to build confidence in firm level responses to ICT use surveys. Researchers in the US, France, Nordic countries and the UK started linking these surveys to business output and employment data to test whether productivity differences between firms could be linked to use of information technology or communications.

Use of firm level data to study the relationship between ICT and firm performance spread across a number of countries as consistent surveys became available. Early studies drew on official and private data sources. Examples of the different approaches adopted include:

- inclusion of ICT capital stock at firm level as a separately identified capital input in total factor productivity (TFP) analysis (Brynjolfsson & Hitt, 2001; Hempell, 2002);
- inclusion of ICT capital alongside other measures of ICT use, such as internet use or number of employees using ICT (Maliranta & Rouvinen, 2003);
- inclusion of ICT capital stock with measures of innovation or organisation change (van Leeuwen & van der Wiel 2003);
- inclusion of measures of computer network use (i.e. behaviour) as an additional determinant of TFP in a productivity regression equation (e.g. Atrostic and Nguyen, 2002).

In 2004 OECD published a portfolio of firm level studies, some comparing ICT impact in different countries, and using similar analytical methods, across 13 countries. For some countries comparisons could only be drawn for manufacturing, and in some (e.g. Germany) links could only be made outside the statistical system. EU member states dominated this first major review which also included Japan, the US, Korea, Australia and Canada.

In 2005 the UK ONS published a set of studies (Clayton et al 2005), which took account of:

- firm level data on IT capital stock, both hardware and software;
- firm level measures of ICT use by employees, of computers and the internet;
- firm level use of e-commerce for both procurement and selling;
- firm level use of communications networks.

These studies showed that while IT investment is associated with increased firm productivity, impacts depend on contingent factors, including whether or not the firm is a multinational, whether it has a US home base, its age, and whether it is a manufacturing or service operation. They also showed that:

- greater ICT use by employees has an additional association with higher productivity, over and above the effect of IT investment;
- organisational differences associated with US ownership influence productivity returns associated with investment in IT hardware for the UK affiliates of US firms;
- returns to IT investment are also influenced positively by firm level possession of skills (measured by employees with degrees) and by investment in fixed capital.

This work was followed by further analysis of investment in high speed internet by firms and the effects of broadband use on productivity (Farooqui S. and Sadun R. 2006). This suggested – using a short time series of firm data – that employee use of fast internet was a useful productivity indicator.

Each of these studies has shown that ICT investment and use by firms has an impact of productivity levels or growth which depends on the sector in which a firm operates, so is business model specific, and which depends on other inputs, related to skills, organisation, or innovation. It is therefore worth considering the work which has been done on 'complementary investment' to ICT.

1.4. Understanding 'complementary investment'

For US, UK, and several other economies, new analysis has recast National Accounts to take account of 'intangible investment', including software, R&D, expenditure on 'non technical' innovation including design, training, organisational change and branding (Hao, Manole and van Ark, 2008). Data is still developing (see EU COINVEST work at www.coinvest.org.uk), but the emerging picture shows that:

- intangible investment is a rising part of activity by firms, and that software and associated business process / organisation investment have been the fastest growing elements;
- intangible investment now rivals investment in fixed assets for the US and the UK,
- much of intangible investment is 'capitalised labour' and so shows a different picture of relative returns to capital and labour from that in official economic statistics;

To interpret this macro framework in firm level or industry level analysis requires us to treat ICT as one agent of innovation and growth. Applying it at firm or industry level needs links between surveys on innovation, R&D, skills, organisation / e-business, other 'intangibles' and business productivity and growth. Our project has set out to do this in countries where data are linkable to the ICT use survey, and to firm output data. A majority of NSIs provide evidence on at least one of these themes.

1.5. Approach to analysis

We have been able to build on earlier studies of surveys, undertaken by the EU and others, on the types of indicators which are most valuable in developing measures of 'impact' for ICTs. The NESIS project had as one of its key recommendations that 'more intensity indicators should be developed on the way from readiness to impact indicators' (Airaksinen A. 2004). The recommendation recognises that intensity of ICT use in firms indicates how far they have changed processes and organisation.

Eurostat's survey includes questions on the degree to which employees are engaged with ICT, but results for most countries on consistent questions about how far ICT is embedded in business processes and transactions was not available until 2008. Our firm and industry level analyses have used earlier intensity measures as the best starting point, looking for relationships between usage and productivity or growth.

Firm level analysis of the drivers of productivity and growth is the foundation of our economic understanding of firm behaviour and performance, and of the influence of market conditions and technology change on competitive behaviour. Insights gained from firm level analysis benefit from much more exhaustive use of data. The range of experience and performance captured in firm level data is much richer, and contains an additional order of magnitude in degrees of freedom, compared to industry level data. Firm level analysis is where we should first pick up signs of impact from use of a technology, by comparing successful and unsuccessful firms. However, firm level analysis, of productivity or growth performance of individual units, may not pick up the 'macro' effects of resource reallocation as successful firms grow, and unsuccessful firms shrink or exit

2. Methods and Data Sources

2.1 Overview

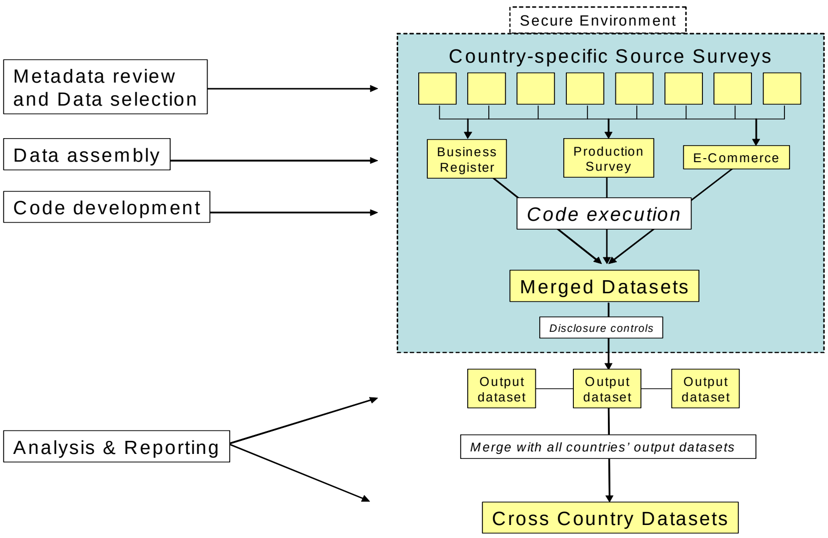
The project methodology is illustrated in Figure 1. It starts with metadata review, to establish what data are held in each National Statistical Institute (NSI) and to identify core variables. Project data are described in detail in the full report, but the variables include:

- variables on ICT-usage by firms, drawn from the harmonised e-Commerce survey ;
- variables which describe economic characteristics and performance of firms, drawn largely from countries' structural business surveys (or Production Surveys);
- information on the population of firms in each project country, from Business Registers .

Firm-level data drawn from all three sources are assembled and processed to create a set of output datasets in each project country. This takes place in a secure environment, reflecting the confidential nature of the firm-level data and is designed to generate non-disclosive statistics, across one or more dimensions such as industry group, size class, year etc.

Datasets are checked for disclosure before being released from their secure NSI environments and compiled into multi-country datasets. Under the legal framework in force in 2008, access to the multi-country datasets is confined to a subset of project participants

Figure 1: Overview of Project Methodology



2.2 Selecting and assembling data

The choice of variables and detailed scope of the analysis has been an iterative process, informed by experience of project members, our metadata survey, the development of the analytical code and investigation of preliminary results, disclosure issues, and other factors. Some examples of issues arising from the metadata phase are as follows:

- ICT investment and capital stocks are highly relevant to analysis of ICT impacts; only two members have firm level ICT investment data, (UK and Netherlands), and they undertook a 'lead country' analysis on this.
- Fast internet capacity and share of broadband enabled workers were added as data showed near saturation of PC-enabled workers; UK research on fast-internet usage also was signifcant.
- Firm-level data on labour skills, such as share of firm's employees with post-secondary education, exists in only a few countries via survey or administrative data. Wages / employee were used as a proxy for skills in analysis across the wider project group
- ICT business integration questions from the e-Commerce questionnaire prior to 2007, are included in analysis which has been run by a 'lead' group of 6 project countries.
- The e-Commerce survey is harmonised across countries, but differences exist in implementation. Translation of the model questionnaire can lead to differences in wording of questions; there are differences in coverage frequency and in sampling methodology.

Business registers provide a reference framework for re-weighting of sample variables, as a business register covers the whole population of firms, and all business registers carry basic information such as firm employment. The project design uses business registers as sources of additional information on firm characteristics, such as age, whether the firm is owned by a multinational, and whether the firm is an exporter. In some countries registers do not contain all these data, and it needs to be added.

NSIs do not hold raw firm-level data in a format that can be addressed directly by the analytical code for this project. A central feature of the project is that *identical* code is run in each NSI. Investment in metadata and code methods has been required to achieve this as coverage and scope of available data varies across project countries.

Although the analytical code is robust to missing variables, certain features of the input data are essential for the code to function properly. These include unique identifiers across all datasets, and consistent assignments to industry classifications

Issues that have arisen in preparing data include:

- Inconsistent variable naming in different vintages of survey data where question numbers change over time. The project code only allows a one-to-one mapping of names, and NSIs must ensure that variables are named consistently.
- Missing variables in some survey years, for example, where new questions have been added to the e-Commerce survey. Users must ensure that all variables that are assigned to project variables are found in every annual input dataset[1].
- Firm level data in Germany are collected and held at regional (Länder) level. These data have been integrated into synthetic national firm-level datasets for this project

Variables used in the project, and data availability across countries are shown in Appendix 1.

2.3 Code development and operation

Marrying identical code with varying national data availability is achieved by building dynamic flexibility into the code. Apart from a small number of core variables without which analysis cannot proceed, the code is designed to allow flexibility in to data availability. In running the code, each NSI assigns country-specific variable names to each variable, entering a null value if the project variable does not exist in their input datasets. The code then builds dynamic lists of variables that exist.

The outputs of the core project code are:

- A set of industry / country indicators built with identical aggregation methods
- A set of results from identical regressions on matched firm-level data in each project country.

Once input data have been assembled and checked, NSIs populate the program run file with local parameters to match project variables with local names, and specify which productivity metrics to use:

- LPQ – log of real gross output per employee. Nominal values are deflated using EU-KLEMS industry level deflators. Since all regressions include time dummies, regression results do not depend on choice of deflator.
- LPV – log of real value-added per employee.
- TFP – a log index of real value added divided by weighted inputs of labour and capital, with weights derived from average factor shares of labour and capital in each industry.
- MFP – a log index of real gross output divided by weighted inputs of labour, intermediate inputs and capital, with weights derived from factor shares of labour, intermediate inputs and capital.

NSIs use as many productivity measures as possible given data available. If source data includes gross output, value added, intermediate inputs and capital stocks, the code generates all four metrics

2.4 Disclosure

The output of the project analysis in each NSI is a set of output files containing statistics derived from the input firm-level data and aggregated over industries, size classes and other categories. The statistics include means and totals, standard deviations, correlations and regression results. Output datasets also include the number of firms represented by each cell. In many cases the number of firms is measured in hundreds or thousands but in some case the number may be quite small.

The process of disclosure control varies across project countries, depending on legal frameworks and local practice. Some countries check outputs and suppress certain results before releasing the outputs to the project co-ordinator. In practice, the number of results suppressed is fairly small.

Once country datasets are approved for release, they are combined with the outputs from other countries and held securely within the project. As some countries reserved their rights to test for disclosure until the project reporting stage, access to the combined datasets is restricted.

2.5 Firm and industry level analytical methods

The project has co-ordinated firm-level analysis of productivity and core ICT metrics, building on previous work and exploiting our comparable linked firm-level datasets. Our interest in comparability of firm level relationships between ICT-usage and productivity across different countries, even if the relationships are not stable across countries or over time. The rationale for this line of work is pragmatic and opportunistic, but built round standard equations of the form

$$tfp_z = b_o + b_1 K + b_2 ICT + b_3 LNW + dummies$$

where:

tfp_z	total factor productivity for firm z
K	*c*apital stock for firm z
ICT	indicator of ICT usage for firm z
LNW	implied firm-level wage taken from firm employment and wage bill
dummies	industry, size-class, year and other dummies such as multinational status.

'Distributed Micro Data' (DMD) analysis is the process of compiling conceptually identical indicators at a relatively disaggregated industry level across multiple countries and time periods. Bartelsman and Barnes (2001) provide two arguments for this approach:

- The DMD approach provides improved timeliness and comparability. It is more timely than, say, waiting for Eurostat to harmonise statistics at source, and more comparable than, say, EU-KLEMS data derived from disaggregation of higher level national statistics;
- The DMD approach involves confronting policy questions with data available, and making successive choices regarding the analyses done. This is a subtle but important point. Given limits on data that can be collected, the DMD approach allows an iterative process between policy questions and data realities.

The iterative process is clearly reflected in this project, first in refinement of the scope of the core analysis and analytical sub-themes, and secondly in the development of the set of data to be collected. For example, fast internet usage was not originally included, but was added as the project evolved. Other variables initially viewed as important – such as firm profitability, international engagement and ICT investment – have either been discarded or confined to sub-themes.

The DMD approach is attractive for international policy analysis. In any single country, the impact of a policy event cannot be measured precisely because there is, by definition, only one observation of that policy event. Cross country datasets can help by providing more observations of policy events. In addition, the DMD approach allows summary statistics from the underlying firm-level data to be captured within the country / industry datasets. For example, the project has generated means data for fast internet usage and productivity metrics by industry, country and year which can be expressed as a scatter plot. Behind each observation in the plot, the DMD dataset contains a suite of variables describing the properties of the firm-level data, such as the variance of the firm-level data, and quartile correlations between each variable and other variables of interest such as wage levels, size of firm etc. This integration of firm-level properties with the richness of comparable data by industry, country and time is a key feature of the approach.

Cross country analysis involves both simple equations of the form shown below, and also two stage estimation systems incorporating selection equations for ICT use.

$$v_{ijt} = a_0 + a_1 ICT + a_2 k^{IT} + a_3 k^{N} + a_4 hrs + dummies$$

where:

v_{ijt}	real value added per employee, in industry i, country j, year t
ICT	indicator of ICT usage for industry i, country j, year t from E-Commerce survey,
k^{IT}, k^{N}, *hrs*	IT capital stocks, non-IT capital stocks and hours worked (taken from EU-KLEMS)
dummies	2 of industry, country and time dummies.

3. Summary of Results

3.1 Where they come from

Project results come from three main types of analytical work:

- an encouraging range of firm level analysis using common metrics and common analytical code with similar data sources, either carried out by local researchers in countries direct from local datasets, or using the data created for the project, plus centrally written code, to run identical regression analysis, for all countries except Denmark and Slovenia.
- groups of countries collaborating on micro data analysis for topics where all have similar firm level data which enable a common analytical framework to be used and compared (eg Netherlands and UK on ICT investment, Sweden, France and Italy on offshoring, Nordic countries on skills, Sweden, Netherlands and UK on innovation, work from Finland on ICT outsourcing).
- industry / country level analysis of ICT impacts, using the large dataset produced by the distributed microdata (DMD) analysis system, from which we have a highly comparable indicators, with the ability to draw reliable comparisons between industries /countries and over time.

Analysis of the properties of linked datasets in the project, using methodologies developed in earlier studies, shows that sample re-weighting, using metadata and methods included in the project, is capable of dealing with most issues of data ‘representativeness’. However this breaks down where overlap between datasets is poor, and we have not advocated modelling in such cases. Linking datasets in many countries, with sampling designs currently in use, leaves the overlap between ICT surveys and firm performance surveys biased towards larger firms. This affects both firm level and the DMD analyses. For impact conclusions to reflect small firms, sampling strategies need to change.

3.2 Firm level – all country results

All 13 countries in the study have produced regression and / or correlation results from firm level data, either individually or using the DMD methodology developed in the project – and in most cases both.

The core ICT use metrics (computer use, e-sales, e-purchases, fast internet enabled or internet using employees) show reasonably consistent, positive, labour productivity effects at firm level across manufacturing in all countries, beyond the six covered by earlier studies. This suggests that productivity impacts related to use of ICT in manufacturing are now well established and transferable across countries.

The same core ICT use metrics have much more varied relationships with labour productivity across services at firm level in different countries; for the UK, France, Nordic countries and Netherlands, positive correlations seen in prior studies are confirmed. In other countries productivity effects are insignificant or even, in one or two cases, negative. Given the importance of services in all the EU economies this is an important difference.

Some correlation is apparent between the countries (Nordic states, Netherlands, UK, France) where ICT use by firms is relatively more intensive and communications infrastructure is strong and the strength of the statistical relationship between ICT use and firm level productivity in services. These differences in impact for services could be explained by a number of factors, including:

- differences in competitive conditions in national services markets,
- productivity gains requiring 'critical mass' in networks and ICT use, and
- measurement difficulties in services which are better tackled in some countries than others.

The common analysis shows limited evidence for productivity impact of e-commerce as a variable on its own, and clear positive relationships between productivity and wages (used later in the analysis programme as an imperfect indicator of skills).

3.3 Firm level – lead country results

3.3.1 ICT capital and ICT use

For Netherlands and UK, data are available on firm level IT capital - hardware and software for the UK, hardware only for Netherlands. This makes it possible to test the impact of ICT use over and above IT capital services in productivity models. The results show impacts differentiated by firm type:

- in manufacturing, intensity of e-procurement shows the strongest link to productivity;
- in distribution services the largest impact on productivity is related to the intensity of use of e-commerce for selling;
- in other, mainly business and financial, service industries the strongest relationship with productivity comes via the proportion of workers with access to high speed internet;
- across all three industry types, IT capital (including software) is positively related to productivity levels in the UK, and with a much larger impact in differentiated services;
- for all three types in Netherlands analysis IT capital (excluding software) is insignificant.

These differences suggest limits to an analytical approach which treats ICT as a 'general purpose technology'. Impacts in different industries suggest different processes at work, through different effects of information technology (IT) and communications technology (CT).

3.3.2 ICT and skills

Three countries, Finland, Sweden and Norway, have 'real skills' data available at firm level, derived by linking employer and employee records. In all three there are strong, significant and simultaneous correlations between labour productivity and the proportion of employees with ICT skills, as well as those with other higher education levels. For both types of skill measures the size of productivity impact make a strong case for wider collection of this type of data across other countries.

In Finland and Sweden similarly strong relationships exist between Total Factor Productivity (TFP) and employee skills (both IT and non-IT), and these relationships are significant alongside the 'fast internet enabled employees' measure mentioned above. For the Norwegian analysis fast internet enabled employees appear insignificant in regression analysis together with non-ICT skills, but, paradoxically, ICT skills remain highly significant. General skills appear to have greater impact in TFP analysis, but ICT skills show up as more significant in labour productivity analysis.

In all three countries it is possible to test complementarity of skills and ICT intensity by adding an interaction term (% skilled employees x % fast internet enabled employees) and only in Sweden does this show up as a significant contributor.

In all three countries wages have a stronger correlation with productivity than do real measures of skills (partly an arithmetic effect as employee compensation is part of value added). The analysis shows that wages have limitations as a direct proxy for skills in productivity analysis, without risk of understating other impacts. However, in analyses where skills data are not available, a proxy based on wages may be useful as a check against overstating ICT impacts due to correlation between ICT use and skills.

3.3.3 ICT and business processes / organisation

Analysis led by UK, Netherlands and Sweden has used measures of ICT business process integration to test methods of combining existing metrics in the Eurostat model ICT use survey in ways which relate effectively to productivity impact.

Swedish analysis, based on a hierarchical specification of business process sophistication, starting with any form of external link working up to use of e-commerce, internet selling and links with suppliers / customers, and also looking at specific types of links, shows that

- the range of indicators linked to productivity has grown through to 2004, and
- evidence in support of positive productivity impacts is strengthening.

However the form of correlation, and electronic links associated with higher productivity, change from year to year.

UK results suggest that the productivity effects of linkages depend on the business type, with manufacturing firms showing stronger correlation coefficients between TFP and the incidence of electronic links to suppliers (associated with supply chain management) and service firms showing stronger productivity effects associated with links to customers.

Regression analysis using firm-level data from UK, Netherlands, Sweden, France, Czech Republic, and Austria suggests that productivity relationships are ‘better behaved’ for manufacturing, while elsewhere there are signs of positive relationships, but that a hierarchical model is not the best approach. Regressions also show that external e-business links have more explanatory power than process links within firms – suggesting that market dynamics are more important that efficiency gains via process coordination. The new ICT use survey (2007/8) provides new data to explore this.

Data for Finland, which alone among EU countries measures organisational issues, IT mobility and IT services outsourcing, shows significant productivity gains associated with:

- mobile access to ICT by workers (suggesting additional gains from flexible work patterns);
- use of outsourced IT services (suggesting additional gains from specialisation).

3.3.4 ICT and innovation

Despite limits to survey overlap, some progress has been made by Sweden, Netherlands and the UK on the role of ICT in innovation, and the mechanism through which much of the productivity gain associated with ICT may be achieved.

UK analysis linking ICT use surveys to questions in the Community Innovation Survey on sources of innovation shows a strong link between use of high speed internet connections by employees within firms (in the ICT use survey) and the ability to innovate using ideas from outside the firm, and outside the customer / supplier chain. This suggests a link between fast internet network use and ability of firms to acquire and manage knowledge in the innovation process, to develop higher sales of new goods or services, or more use of new processes.

Evidence from Sweden and Netherlands shows that ICT use – reflected in the proportion of fast internet linked employees and levels of e-commerce – is related to the intensity of firms’ new products and services sales. This may reflect network effects in knowledge management, in the effectiveness with which firms are able to convert knowledge into new products and services, and in the speed with which they are able to commercialise them. The impact of e-commerce in Netherlands analysis may show that benefits of e-commerce for innovation (which prior research has missed) is now visible.

Analysis across all participating countries using DMD shows that in industries which have relatively high levels of ICT use on the core metrics, there also tend to be higher absolute amounts of market share change (or ‘churn’). This is consistent with the view that ICT intensive industries in Europe show the tendency seen in the US by Brynjolfsson et al, for successful firms to be better able, and quicker, to replicate market share winning innovations across production and distribution networks.

From Sweden and Netherlands there is initial evidence, despite the limits of overlap between production, ICT and innovation surveys, that productivity effects of ICT use are associated more strongly through the 'indirect innovation' effect (percent new products / services) than through ICT use measures directly. The Swedish analysis tests the relative strength of direct and indirect productivity effects and concludes that the ICT => innovation => productivity channel is significantly stronger than the direct ICT => productivity channel for the individual firm. The Swedish evidence is concentrated on larger firms due to sampling effects.

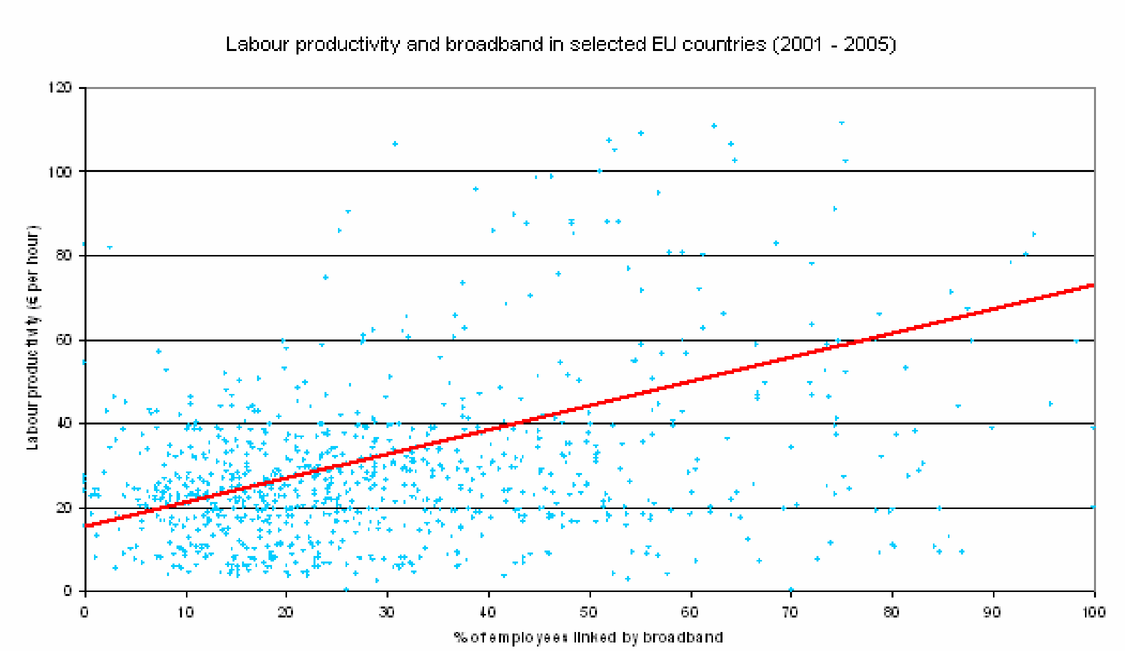
Evidence from Netherlands suggests that ICT use can substitute in productivity equations for the CIS process innovation indicator, indicating that ICT use may be a good proxy for process innovation. This provides statistical evidence for a position argued by researchers, that in service industries particularly ICT introduction is often the embodiment of process change.

As noted above, this analysis has stretched the statistical limits of overlap datasets – showing that the intersection sets of two surveys are often good enough for firm level analysis, but it is much more difficult to achieve significant analysis from matching three or more surveys. This has so far limited the ability of other NSIs to contribute to the ICT / innovation analysis.

3.4 Industry / country level results

Analysis across all 13 countries using National Accounts based treatment of productivity (developed by EU KLEMS) shows worthwhile improvement in explanatory power, when including ICT use indicators, constructed using our metadata to ensure comparability rather than 'official' ICT investment data. ICT metrics delivered by our project are more comparable both in source and in compilation.

Figure 2: Productivity and broadband enabled employees by industry / country / year



High speed internet use by workers shows up in cross country regression analysis as a more powerful indicator related to productivity than e-commerce measures, and as the most effective ICT explanatory input for the period 2000/1 – 2004/5 over which most of our international data are available. This relationship (Figure 2 where each dot represents an industry. country, year observation on productivity and ICT-usage) is stronger at industry level than at firm level, due to reallocation effects within industries as successful firms grow. However industry analysis by country suggests that the impact of high speed internet use by employees is not uniform. It is positively correlated to productivity in those countries where ICT adoption is highest, but negatively related to labour productivity in Germany, Austria and Italy for 2001-2004. This is consistent with the national results obtained with firm level analysis, and suggests that returns depend on 'critical mass' network effects.

A more advanced approach to analysis is set out below, in a regression which looks simultaneously at adoption of ICT and its impact. In the two equations below, a) models the industry / country output effects associated with ICT use and other inputs, b) models the adoption of ICT use as a function of average skills (reflected by wage levels), the proportion of capital accounted for by ICT, the proportion of high skilled workers, and the 'churn' in firm output within each industry, represented by the difference between the upper and lower quartile firm growth rates.

$$a: v_{ijt} = a_0 + a_1 DSL\% + a_2 k^{IT} + a_3 k^{N} + a_4 hrs + dummies$$

$$b: DSL\%_{ijt} = b_0 + b_1 w_{-1} + b_2 Cap\%_{-1}^{IT} + b_3 HiSkl_{-1} + b_4 Churn + dummies$$

where

v	= (log) real value added	W	= Average wage
Kit	= ICT capital service	Cap%it	= ICT-capital as share of cap.
Kn	= Non-IT capital service	HiSkl	= High skilled worker share
Hrs	= input hours	DSL%	= Broadband enabled workers
c,i,t	= country, industry, time dummies	Churn	= Interquartile range of firm-level growth rate

This analysis takes account not only of the 'within firm' productivity effects on which firm level analysis focuses, but also of the competitive dynamics and reallocation of resources which takes place within industries due to differential growth, and to entry and exit. The analysis is able to combine indicators built using the metadata approach with measures available at industry level from National Accounts and labour market statistics including productivity, growth, and – for most countries – ICT capital.

Coefficient	**Variable**	**DSL%**		**Internet%**	
a1	ICT-indicator:	1.24	.90	1.20	1.05
a2	Kn	.35	.27	.34	.27
a3	Kit	-.07	.05	-.08	.05
a4	Hrs	.72	.68	.72	.68
b1	w(-1)	.24	.02	.30	.01
b2	Cap%it	.31	.20	.32	.17
b3	HiSkl	.18	.38	.19	.33
b4	Churn	.30	.15	.28	.14
	dummies	c,t	i,t	c,t	i,t
	D.F.	659	646	649	646

The ICT indicators (except Kit) are statistically significant in all specifications.

Results of ICT use adoption models using this dataset are consistent between countries / industries, and the adoption rate is usually strongly associated with worker skills (measured by wages). Our firm level productivity regression equations are robust to inclusion of wages as a proxy for skills.

Other, more advanced, analysis combining this work with OECD country measures of labour market flexibility suggests that more intensive ICT using industries make the fastest progress in catching up to the best practice 'productivity frontier' in economies where there is more labour flexibility.

3.5 Fit with other new work

The analysis in this project, and detailed in our full report shows that coordinated microdata analysis across countries makes a valuable addition to our understanding of ICT adoption and its impact on economic performance. We have seen that:

- ICT use is related at firm level to performance in different ways in different industry types
- In manufacturing the productivity effects seem well established; services show more vasriation
- ICT use metrics are, in many cases, more powerful explanators of performance than investment
- ICT returns are related to 'critical mass' network effects, and these evolve over time
- ICT use affects, or is afffected by, competitive dynamics at firm / industry level

This last conclusion is entirely supportive of recent work in the US by Eric Brynjolffson which shows, in a range of cases studies, how ICT and network use enables experimentation and process innovation in network intensive firms. This work shows how successful experimenters, especially in services, use network and ICT based 'enterprise architecture' to scale up their successes and achieve market advantage.

The churn effects, seen in the equations above, suggest that identical dynamic processes are under way in the EU data. Both are also consistent with the relationships seen earlier in the firm level results on ICT enabled processes, which show that customer links in services (through which Brynjolsson's experimentation often occurs) are most strongly associated with improved performance.

Further work at Statistics Netherlands (van Leeuween et al 2009) shows that ICT is one of a set of inputs which stimulates product, process and organisational innovation. These modes of innovation, in different combinations in different industries, are associated with productivity gains

The implication is that ICT and networks are bringing important changes in business models and in industry dynamics. The analytical approach we have developed in this project delivers a valuable way of understanding these changes, and is worth pursuing further.

4. Where next?

ONS and project partners are in discussion with Eurostat over scope and funding for the next stage of the project. For this, we envisage a broadening and deepening of the work in the first phase.

4.1 Broadening

Key priorities for the next stage are:

- to extend the number of countries taking part. So far Eurostat have interest from Austria, Bulgaria, Czech Republic, Germany, Denmark, Finland, Ireland, Italy, Luxembourg, Malta, Netherlands, Norway, Poland, Sweden, and UK. It would be helpful to add further member states to this group to secure comprehensive coverage;
- to extend the length of panel data used in the first study and explore different analytical approaches to building panels of linked data to maximise information on firm dynamics;
- to make full use of the 2007 e-Commerce survey which has common data across all countries on business process links, building on the indicative conclusions from the first project;
- to extend the range of variables to include other measures of, and inputs to, innovation, following what we know from the first study and from the van Leeuwen / Polder work. This will require us to extend the DMD method to innovation surveys, skills measures, and perhaps to measures of organisation change, location, profitability etc.

One important development since the submission of our first project report and recommendations is that EU statistical regulations have been amended to make it easier to share non-disclosive data (on which the project method depends) between statistical offices and researchers. This should extend the range of data sources which can be used, and the number of countries able to take part.

4.2 Deepening

Key priorities on this dimension for the next stage are:

- to develop the firm-level analysis, using longer panels, to include testing and controlling for endogeneity;
- to search for better evidence - across more countries - of the differences in ICT impacts in different business types and models. The motivation for this is the hypothesis that ICT and networks transform business models in different ways, depending e.g. on the form of the value chain. It will help to have better analysis of this to construct measures of 'ICT impact';
- to examine what features of ICT make a difference in the economic downturn;
- to investigate complementarities between ICT and intangible investments, especially in training and skills, R&D, organisational capital and other inputs to innovation.

We welcome input from all NSI's and potential partners in taking the next steps forward, in what we hope will be a significant step for the statistical system, and the integration of data describing technology and behaviour with economic statistics.

ONS, 27th August 2009

Appendix 1: Data available for the project by theme and country

	AUT	CZE	DNK	FIN	FRA	GBR	GER	IRE	ITA	NLD	NOR	SLO	SWE	TOT
Firm characteristics														
Employment on BR	●	●	●	●	●	●	●	●	●	●	●	●	●	13
Sample Weight on PS	●	●				●	●		●	●			●	7
Sample Reweighting	●	●			●	●	●		●	●	●		●	9
Multinational flag on PS		●			●	●				●			●	5
Ownership flag on PS		●		●	●	●		●		●		●	●	8
High growth firms	●	●		●	●	●	●	●	●	●	●	●		11
Gazelles (age on PS)				●	●	●			●			●		5
Gross output on PS	●	●	●	●	●	●	●		●	●	●	●	●	12
Value added on PS	●	●	●	●	●	●	●	●	●	●	●	●	●	13
Nominal materials on PS	●			●	●	●	●	●	●	●		●	●	10
Payroll (wage) on PS	●	●		●	●	●	●	●	●	●	●	●	●	12
Capital Stock on PS	●	●		●	●	●	●		●	●	●	●	●	11
Productivity Variables														
Productivity LPQ available	●	●	●	●	●	●	●		●	●	●		●	11
Productivity LPV available	●	●	●	●	●	●	●	●	●	●	●		●	12
Productivity MFP available	●		●	●	●	●	●		●	●			●	9
Productivity TFP available	●	●	●	●	●	●	●		●	●	●		●	11
ICT Key Variables														
PC	●	●	●	●	●	●	●	●	●	●	●	●	●	13
Web	●	●	●	●	●	●	●	●	●	●	●	●	●	13
Epurch	●	●	●	●	●	●	●	●	●	●	●	●	●	13
Esales	●	●	●	●	●	●	●	●	●	●	●	●	●	13
Inter	●	●	●	●	●	●	●	●	●	●	●	●	●	13
DSL	●	●	●	●	●	●	●	●	●	●	●	●	●	13
PCpct	●	●	●	●	●	●	●	●	●	●	●	●	●	13
Epurchpct	●	●	●	●	●	●	●	●	●	●	●	●	●	13
Esalespct	●	●	●	●	●	●	●	●	●	●	●	●	●	13
Interpct	●	●	●	●	●	●	●	●	●	●	●	●	●	13
Intrapct	●	●	●	●	●	●	●	●	●	●	●	●	●	13
DSLpct	●	●	●	●	●	●	●	●	●	●	●	●	●	13
ICT Other Variables														
Mobility				●										1
IT Outsourcing				●										1
IT Business Integration Links	●	●			●	●				●			●	6
Other firm-level data														
ICT investment						●				●				2
Trade flows					●				●				●	3
Human capital / Skills				●							●		●	3
Innovation						●				●			●	3

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