ICT impact assessment by linking data across sources and countries

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Abstract

This Eurostat funded project involving 13 countries, and academic contributors, is designed to meet two key objectives for the European Statistical System

- to develop new indicators on the economic impact of ICT in business without increasing the burden of surveys on respondent firms, and
- to extend consistent analysis of ICT impacts to new countries.

Its results are achieved through data linking across surveys, including (for all 13 countries) the common EU ICT use survey for business, the Structural Business Survey and business register and, for some 'lead' countries, surveys in skills, international sourcing, ICT investment and innovation. Starting from evidence on ICT and productivity from earlier single country studies using firm level data linking, the study group agreed a set of core metrics from common surveys which all countries could analyse, and 'lead' analyses based on data available in groups of countries with additional data. Each is based on the principle that important indicators are those related to productivity and growth impacts of ICT.

In addition to firm level analysis the study has developed an industry based analysis method, using a comprehensive set of metadata, to produce ICT and other indicators on a comparable basis across industries and countries. This allows technology use data to be combined with other – aggregate – economic data in productivity and growth analysis, including EU KLEMS.

The results show additional productivity effects associated with ICT through competitive substitution over and above 'within firm' effects. Evidence from the study suggests that productivity effects associated with ICT use in manufacturing are relatively consistent across the participant countries, However, effects in services are more diverse, depending on both type of industry, and the level of ICT use in the country. Firm and industry level analyses also suggests that the productivity impacts of ICT are associated with its role in originating innovation, and in enabling firms to replicate successful innovation across markets.

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1) Introduction and Background

ICT indicator development

'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. Eurostat began to develop approaches based on best practice among its member states. In 1999, the US Bureau of Census made its first (and so far only) survey of computer network use in firms.

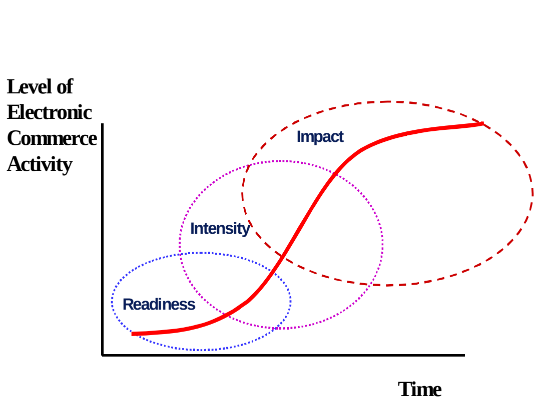
The OECD's 1998 ministerial meeting on ICT and e-commerce, initiated both a policy framework and statistical approaches for challenges posed by new technology which:

- made it possible to conduct business electronically ignoring international borders;
- created commercial links bypassing traditional channels of distribution and payment;
- provided opportunities for productivity improvements which did not appear (at least at first) to show up in the statistics.

OECD 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.

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



Impact; changes in behaviour, economic structure and performance as result of use

Intensity / use; measures of the proportion of firms, individuals who adopt, and the amount of use

Readiness; ability of firms, individuals, government to adopt technology

Figure 1 OECD 'adoption' framework

The 'S curve' approach, borrowed from Statistics Canada, was prominent in the first 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. The assumption was 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.

OECD developed definitions of e-commerce in use today, and model surveys and metrics which still form the basis of much international comparison work. Most metrics were aimed at the 'use' element of the framework, measuring the behaviour of firms and households, their ownership and use of ICT goods and services, and the proportion or value of sales and purchases executed electronically. There were also measures of 'readiness', gauging attitudes to and opinions of e-commerce or the internet, to try assess barriers to firms' or individuals' use (for non-users), or the self assessed benefits (for users).

Self assessment questions, which covered 'readiness' and 'impact' measures to help policymakers, were the least robust elements of the early framework. An example of the difficulty in interpreting questions relating to 'barriers' came from early results suggesting firms experiencing most barriers were also those which had done most in terms of adoption. Perceptions are unreliable guide to outcomes or behaviour. International comparisons of household surveys suggested perceptions of risk (of fraud etc) were lower in the UK – where incidence was higher – than in other EU economies where incidence was lower.

How indicators have been used for policy

ICT measurement effort was given new impetus by adoption, in 2001, of the Lisbon strategy to promote Europe as a 'dynamic knowledge based economy'. The Council of Ministers committed to policies through which innovation, including ICT use, and designed to promote inclusion and sustainability, would break the trend of poor relative productivity performance of the EU compared to the US. The programme used an 'open method of coordination', with peer review of progress using indicators. This needed a clear evidence framework at all levels.

The EU framework for indicators to support the Lisbon programme covered metrics for the overall economy, for employment, market reform, distributional and environmental effects, and, not least, for innovation. The evidence needed for open comparison of national policy environments was contained in the EU 'Structural Indicators' dataset, developed in 2001/2, and subsequent reviews. This is designed to provide a comprehensive picture of the outcomes of policy (growth, productivity, employment) and of underlying drivers (skills, investment, entrepreneurial activity, technology, training).

Indicators for innovation in the structural indicators include ICT investment and e-commerce use. ICT investment was measured using private sector estimates, because national accounts estimates were not considered reliable, but consistent measures of use of electronic transactions in EU member states were delivered through development of the ICT use survey, led by Eurostat. With a coordinated programme, and knowledge sharing among the EU statistics offices, experience in 'what worked' for ICT use surveys grew rapidly. The survey grew from initial concentration 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, skills, and other areas.

In addition,to headline metrics 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, but with the largest section on business metrics. Examples of broader integrated sets of indicators used for policy management include:

- the 'e-government indicators', surveyed for DG INFSO by Cap Gemini Ernst and Young, (Web-based Survey on Electronic Public Services 2002) which tracked availability and sophistication of specific government services in all EU countries, to classify the level of interactive service from 'provides information', through 'provides forms for off line completion' to 'complete transaction'. This is a user centred test of e-business process use.
- UK's e-commerce benchmarking framework, by Booz Allen (Booz A H. 2002), assembled official and unofficial data from leading countries, on readiness / use / impact of ICT for business, citizens and government, and used to identify key areas for focus of government activity, as well as gaps in statistics. Its measures of 'impact' were limited to behaviour change measured through ICT use (e.g. consumer purchases over the internet) and macro-economic productivity estimates of ICT impact via growth accounting.

Development of ICT impact analysis - macro

Early assessments of the economic impact of ICT adoption 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 decision, in 1993, to treat software investment as an asset under 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 in its 2003 report (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 the strength of ICT investment in service industries – whereas much of the early impact analysis has been focused on manufacturing for measurement reasons. While it showed ICT investment as a contributor to output growth and productivity, differences in impact 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 as ICT investment grew, and in some it seemed to fall.

A major difficulty in these early assessments of ICT impacts for policymakers was that estimates of ICT investment in macro-economic data were not consistent across countries. Principal reasons for the differences were:

- different estimation methods for software investment (first included as an asset in ESA 1995) with surveys in place in some countries but not others, and major variations in the treatment of 'own account' software written within firms for their own use;
- lack of consistent deflators for hardware and software, and much international debate on the 'hedonic' approach used in the US to quality adjust computer and software prices.

Macro economic estimates through the late 1990s / early 2000s were also complicated by the distortions of the 'dot com boom' which changed market conditions to such an extent that productivity gains were attributed to this rather than to longer run structural or technological change. Productivity gains could be attributed to the (fast growing) ICT producing industries, but universal benefits from investment by ICT users were less clear.

Analysis at industry level is the focus of more recent work in the US, and the EU. 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 in industries speeds up diffusion of new, successful, business models by 'winning' firms, and is associated with more market share change within these 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 are still under review, but interim outputs show significant differences across countries, and between the EU and the US, in the growth accounting impact of ICT investment. However, 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;
- 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. Reasons why IT investment may be inconsistently recorded in official data include:

- the difficulty of extracting survey data from firms on software investment, both on own account work by their own employees which is usually not recorded in accounting systems as capital, and on software which is embedded in IT system purchases;
- differences between countries in the detail with which deflators are applied to different elements of IT, hardware, purchased packaged (i.e. standard) software, purchased bespoke (one off project) software and own account software;
- differences in application of the internationally recommended method for calculating own account software investment across countries.

These issues are explored in work by the UK Office for National Statistics (Chamberlin et al 2006). The implications are that ICT investment may be a useful directional indicator for change in technology investment. However, as the proportion of IT investment becomes more heavily weighted in favour of software rather than hardware, and the proportion of software creation outside the IT industry grows, reliability of official IT investment estimates may become harder to guarantee rather than easier.

An additional factor which affects the pattern of ICT investment, revealed by this project, is the growing importance of IT service outsourcing. Earlier studies have shown the productivity effects associated with offshoring of IT enabled services. Finnish analysis for this project, 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, from the Eurostat firm level survey, may be a better way of assessing this.

Firm level impact analysis

Early firm level use surveys, piloted by OECD, were implemented in Canada, Scandinavia, Australia and the US in the late 1990s. Starting in 2001 the EU began a sustained programme of implementation and development of ICT use surveys, in which member states were supported in developing practical survey instruments around a common core of questions.

By 2002/3 enough experience had been gained to build confidence in the firm level responses to most questions included in EU ICT use surveys. Researchers started linking the surveys to NSI 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 soon as consistent surveys became available. Early studies drew on both official and private data sources and used different methodologies. Some examples of some of the different approaches adopted are:

- 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 on innovation and / 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. In most cases scope for cross-country comparison was limited to two or three NSIs, because of differences in ICT use surveys or in scope to link to other sources. For some countries comparisons could only be drawn for manufacturing, and in some (e.g. Germany) links could, at that time, 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 Office for National Statistics published a set of studies (Clayton et al 2005), based on firm level data, 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, the effects depend on contingent factors, including whether or not the firm operates as 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;
- e-commerce uses for selling and for buying have different productivity effects; for manufacturing e-procurement has a stronger productivity influence;
- organisational differences associated with US ownership influence productivity returns associated with investment in IT hardware for the UK affiliates of US firms;
- greater communications expenditure by firms can also enhance productivity effects associated with IT investment;
- 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 a relatively short time series of firm level data – that early broadband adoption by UK firms was biased towards those with high prior productivity, but that subsequent performance showed gains from adoption. The analysis showed that employee use of fast internet connections was a useful productivity indicator, in combination with others

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;
- depends on other inputs, related to skills, organisation, or innovation.

It is therefore worth considering, as part of the background to this project, the work which has been done on 'complementary investment' to ICT.

Increasing understanding of 'complementary investment'

Recent productivity analysis (at macro level) suggest an alternative view of traditional accounting approaches to assets in economic aggregates, beyond the standard System of National Accounts, which treats software as investment but treats as intermediates most other 'knowledge' inputs to the production process. For the US and the UK, and a number of other developed economies, new analysis has recast National Accounts to take account of 'intangible investment', including R&D, expenditure on 'non technical' innovation including design, training, organisational change and branding.

Data on these areas are still developing, but the overall picture which emerges from the studies is a growth accounting analysis which is more intuitively sensible over the 1990s and the early part of the 2000s. It shows that:

- intangible investment is a rising part of activity by firms, even if it does not show up in balance sheets, and that software and the 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;
- this treatment captures the major investment by US and UK firms in the late 1990s associated with major business change.

To interpret this macro framework using firm level or industry level analysis requires us to treat ICT as one agent of innovation and growth. Applying this framework at firm or industry level, requires linking to surveys on Innovation and R&D, skills, organisation / e-business links, other 'intangibles' and business performance, productivity and growth.

Our project has set out to do this in specific countries where data are available and linkable to the ICT use survey, and to business output data. This is easier in NSIs which have more developed statistical infrastructure, and greatest capability for data linking analysis. But a majority of NSIs in the project have provided evidence on at least one of these themes.

Overall approach to analysis

In addressing the objectives set by Eurostat in this project, in addition to linking surveys and data sources we set out to link micro (firm level) and macro (industry or whole economy level) analysis. This has advantages, but also poses challenges for statistical 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, in addressing the relationships between ICT use and business organisation and business processes, 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 the intensity of ICT use within firms is indicative of how far they have changed processes and organisation, or of their capability to change in future. It also provides a useful link to the conceptual macro work on complementary investment.

Eurostat's survey includes questions on the degree to which employees are engaged with ICT, but results for most countries on new questions about how far ICT is embedded in business processes and transactions will not be available until 2009. Our firm and industry level analyses have used intensity measures now available 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. It can be argued, in considering capitalisation of software and R&D in National Accounts, that we should only treat these activities as investment in economy if we can show how they behave as assets for individual firms. This principle has driven much microdata work on innovation.

In addition, 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. This is usually well before the successful firms have a sufficient impact on industry performance to permit analysis to identify it at the higher level. However, we need to recognise that firm level analysis, of productivity or growth performance of individual units, may not pick up the 'macro' effects of resource reallocation as successful firm grow, and unsuccessful firms shrink or exit.

2) *Methods and Data Sources*

Overview

The project methodology to develop indicators is illustrated in Figure 2. It starts with a metadata review, to establish what data are held in each National Statistical Institute (NSI) and to identify the variables which should constitute the core dimensions of the project.

The data are described in detail in the report, but the variables include:

- A set of variables on ICT-usage by firms, drawn from the Eurostat harmonised e-Commerce survey (EC);
- A set of variables which describe the economic characteristics and performance of firms, drawn largely from countries' structural business surveys (denoted Production Surveys (PS) in this report);
- Some information on the overall population of firms in each project country, taken from Business Registers (BR).

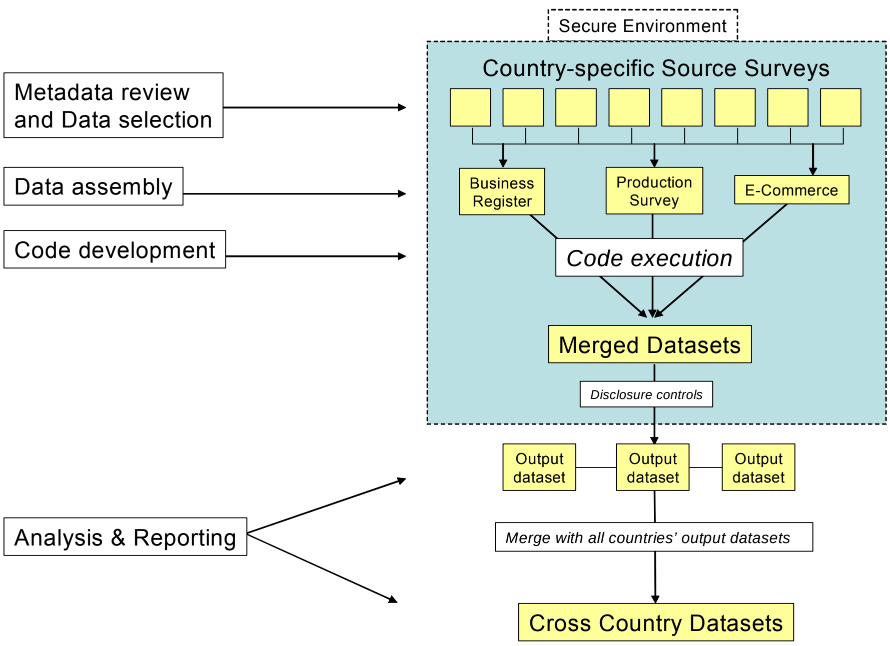


Figure 2: Overview of Project Methodology

Firm-level data drawn from Business Registers (BR), Production Surveys (PS) and E-Commerce surveys (EC) are assembled and processed to create a set of output datasets in each project country. This activity normally takes place in a secure environment, reflecting the confidential nature of the firm-level data. However, the processing is designed to generate *a priori* non-disclosive statistics, being aggregates of firm-level data across one or more dimensions such as industry group, size class, year etc. The process also generates certain direct project outputs such as regression statistics.

Datasets are checked for disclosure before being released from their secure NSI environments and compiled into multi-country datasets. At the present time, access to the multi-country datasets is confined to a subset of project participants. One recommendation of the project is that consideration should be given to providing wider access for research purposes.

Metadata review and data selection

The choice of variables and detailed scope of the analysis has been an iterative process, informed by the knowledge and experience of project members, responses to a metadata survey conducted at an early stage of the project, issues that have arisen in the development of the analytical code and investigation of preliminary results, disclosure issues, the format and scope of the EU-KLEMS database and other factors. Some examples of issues arising from the metadata phase are as follows:

- Unique firm identifiers; the source data in each participating country depends on unique firm identifiers which provide the key to match firms across different surveys and datasets. Identifiers are part of a longitudinal business register which (a) tracks firms over time and (b) is used as a sampling frame for surveys of the business sector, including the structural business surveys and E-commerce surveys.
- ICT investment and capital stocks are highly relevant to analysis of ICT impacts. However, the metadata survey showed only two project members with firm level ICT investment data, and it was decided to exclude it from the core firm level analysis . The two members (UK and Netherlands) undertook a 'lead country' analysis on this.
- Fast internet capacity (*DSL*) and the share of workers with access to such capacity (*DSLPCT*) were added in the light of data showing near saturation of PC-enabled workers (*PCPCT*) and of the results of research using fast-internet usage in the UK.
- Firm-level data on labour skills, such as the share of the firm's employees with post-secondary level education, was added, despite the fact that only a minority of countries have direct survey or administrative data at firm level. Wages / employee were used as a proxy for skills in analysis across the wider project group
- Some ICT business integration questions from the e-Commerce questionnaire have not been included in the core specification, due to incomplete coverage and the costs of data assembly. These data have, however, been included in analysis which has been run by a 'lead' group of 6 project countries.

The e-Commerce survey is harmonised across countries, but one finding of the metadata review is that differences exist in its detailed implementation. Translation of the model questionnaire can lead to differences in precise wording of questions; there are differences in coverage (particularly of optional elements in the harmonised questionnaire), differences in frequency and in the sampling methodology.

Business registers are used to provide a reference framework for re-weighting of sample variables, exploiting the property that the business register covers the whole population of firms, and all business registers carry basic information such as firm employment. However, employment on business registers is not always updated and typically is below employment reported by firms in the structural business survey.

The project design assumes business registers are a source of additional information on firm characteristics, such as age of firm, whether the firm is owned by a multinational organisation, and whether the firm is an exporter. In some countries registers do not contain all these data.

The full set of variables used in the project is shown in Table 1. Appendix 1 at the end of this paper shows how data availability by theme is distributed across countries.

Table 1 – Core Variables and Variables used for 'Lead' Analysis

Variable Name	Description	Domain
E-Commerce Survey Variables		
DSL	Firm has broadband	Boolean (1=Yes, 0=No)
DSLpct	% of workers with access to broadband	Percentage (Range 0–1)
Epurch	Firm orders through Internet (or EDI)	Boolean
Epurchpct	% of orders through Internet (or EDI)	Percentage
Esales	Firm sells through Internet (or EDI)	Boolean
Esalespct	% of sales through Internet (or EDI)	Percentage
Inter	Firm has Internet	Boolean
Interpct	% of workers with access to Internet	Percentage
Intra	Firm has intranet	Boolean
Intrapct	% of workers with access to intranet	Percentage
PC	Firm uses computers	Boolean
PCpct	% of workers using computers	Percentage
Web	Firm has website	Boolean
Production Survey Variables		
Country	Country code	Text string
Year	Year to which data pertain	Numerical string
Euk	Industry classification	Text string
Sz_Cls	Size class (based on employment)	Numerical class (0 – 7)
Frgn_Own	Multinational dummy	Boolean (1=Yes, 0=No)
SRC	Tabulation type (for sorting data)	Numerical class (1 – 10)
NQ	Nominal sales	Level
NV	Nominal value added	Level
NM	Nominal material inputs	Level
Pay	Payroll	Level
E	Employment	Level
Wage	Derived Pay/E	Level
LnWage	Log of Wage	Level
K	Capital stock	Level
Productivity Variables (Computed by code)		
LPQ	Labour productivity based on real sales	Level
LPV	Labour productivity based on value added	Level
TFP	TFP (Value added with capital and labour)	Level
MFP	MFP (Gross output with capital, labour and materials)	Level
Additional Variables		
Emp_BR	Number of employees given in BR dataset	Level
Export	Export dummy, exporter = 1 non-exporter = 0	Boolean (1=Yes, 0=No)
Age	Age of firm in years	Level
Frgn_own	Foreign owner (Business Register)	Boolean
Hge	High-growth enterprises) (Computed by code)	Boolean
Gzl	Gazelle (Computed by code)	Boolean
Skills		
Hkpct	Number of employees with upper secondary education	Level
Hkitpct	Number of employees with IT upper secondary education	Level
Hknitpct	Number of employees with non-IT upper secondary education	Level
ICT Integration		
intlink_1	Internal link to systems for re-ordering replacement supplies	Boolean (1=Yes, 0=No)
intlink_2	Internal link to invoicing and payment systems	Boolean
intlink_3	Internal link to systems for managing production, logistics or service operations	Boolean
extlink_s	External links to suppliers' business systems	Boolean
extlink_c	External links to customers' business systems	Boolean
intlink_1	Internal link to systems for re-ordering replacement supplies	Boolean
intlink_2	Internal link to invoicing and payment systems	Boolean

There are two methods of adding additional data sources to the core set:

- Include additional variables from the input datasets; an example of this approach is the analysis of data on ICT business process integration (BPI). These data are drawn from the E-Commerce survey but are not included in the core project specification.

- Include data from separate datasets, such as firm level data on ICT investment or capital stocks, data from Community Innovation Survey (CIS), and data on trade and foreign direct investment. As long as such data can be matched through a unique firm identifier we can modify the project specification to incorporate it.

Data assembly

It is unlikely that NSIs hold raw firm-level data in a form and 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.

The analysis specification assumes that EC and PS input data is stored in annual datasets of the form "PRE_ECYYYY" and "PRE_PSYYYY" where "PRE_EC" and "PRE_PS" are common prefixes and "YYYY" is the year to which the data pertain (not the year when the survey was conducted, an ambiguity picked up at the metadata stage). The analytical code is specified to read a single BR input dataset, containing register information stacked over all years.

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 firm identifiers in each of the BR, EC and PS datasets, to enable firms to be matched across different datasets, and the year to which data apply is also mandatory[1].
- Every firm must be assigned to an industry code. Country specific industry codes are linked to the uniform project industry classification through a user-defined concordance table, which assigns each country specific code to one of the project industry codes.

Issues that have arisen in preparing data include:

- Inconsistent variable naming in different vintages of the source data where survey question numbers have changed 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 read by the code. Where variables are missing, place-holders must be added and populated with missing values[1].
- It may be necessary to pre-merge data from different source files into the input datasets to be read by the project code. For example, the code is specified to read multinational and foreign ownership flags, and the age of the firm, from the BR input dataset, and data on labour skills (if they exist) from the PS dataset. Where data exists outside the business registers and structural business surveys, it must be merged in.
- 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.
- There are rules for data cleaning. Boolean variables such as *PC* should take the values 0, 1, or missing. Continuous variables such as *PCPCT* should be bounded 0-1 (or missing) in all survey years. Similarly, variables denominated in national currency units in the PS survey, such as value-added, should be in consistent units across survey years.
- Users must ensure that their concordance table links every industry code that appears in their BR, PS and EC datasets to the project industry classification.

Code development

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, project members in each NSI assign 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.

Similarly the code is dynamically flexible with respect to time periods and will read all annual EC and PS input datasets located in an input directory named by the user in setting up the program run control file. This feature also deals with non-consecutive surveys.

The outputs of the core project code are:

- A set of industry / country indicators built with identical aggregation methods
- A set of results based on running identical regression specifications on the underlying matched firm-level data in each project country.

The code runs in SAS with a duplicate version available in STATA. The SAS code was developed by Eric Bartelsman and tested on UK firm-level data by ONS. The STATA version was developed by ONS, and tested against the SAS outputs using ONS firm-level data.

Running the code

Once input data have been assembled and checked as described, it is straightforward process to execute the analytical code. NSIs must populate the program run file with local parameters to match project variables with local names, and specify which of up to four productivity metrics to use:

- LPQ – log of real gross output per employee. Firm-level data are normally available in nominal terms. Nominal values are deflated using EU-KLEMS industry level deflators. These deflators are not the most disaggregated available for each country, but their methodology is common to all project countries and consistent with the aggregation structure of the project. 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 the average factor shares of labour, intermediate inputs and capital.

NSIs use as many productivity measures as possible given local data availability. If the source data include gross output, value added, intermediate inputs and capital stocks then the code can generate all four productivity metrics. If inputs data are not available, then MFP cannot be computed. If there are no "k" data then neither TFP nor MFP can be computed, and so on.

Disclosure

As shown in Figure 2, 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.

The 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. An example might be for variables drawn from the linked PS-EC surveys for small industries and small size classes.

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 (for example by suppressing all outputs where the number of underlying firms is small); other countries carry out no disclosure tests at this stage, but reserve the right to check for disclosure at the project reporting stage. In practice, the number of results suppressed is fairly small.

Once country datasets are approved for release, they are sent to the project co-ordinator and combined with the outputs from other countries and held securely within the project. As some countries have reserved their rights to test for disclosure until the project reporting stage, access to the combined datasets is restricted to nominated and approved researchers from within the project, and is restricted to research conducted under the terms of reference of this project. This part of the process will need to change if the method is more widely used. Data held in the cross-country datasets are purely for research and not official statistics.

Methodology: Rationale and Feasibility

The data-linking analysis used is a combination of co-ordinated firm-level analyses carried out in each separate country, and a programme of analysis of country / industry datasets built from aggregation of comparable linked data in all (or most) countries in the project.. It may help to illustrate methodologies by comparing regression specifications:

(i) Regressions on industry/country (DMD) data

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

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, such as DSLPCT
k^{IT}, k^{N}, *hrs*	IT capital stocks, non-IT capital stocks and hours worked (all three variables taken from EU-KLEMS dataset
dummies	2 of industry, country and time dummies.

(ii) Regressions on firm-level data

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

Where:

tfp_z	total factor productivity for firm z
K	capital 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.

The Distributed Micro Data (DMD) approach

In this project, DMD refers to the process of compiling conceptually identical indicators at a relatively disaggregated industry level across multiple countries and multiple time periods. Bartelsman and Barnes (2001) provide two arguments for this approach:

- The DMD approach provides improved trade-off between 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 a process of making choices regarding the analyses that can be done. This is a subtle but important point – clearly there are limits on the data that can be collected, and equally there are policy and other research issues that cannot adequately be addressed by the data that are available. Effectively, the DMD approach involves an iterative process between policy questions and data realities.

This 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 in the dataset but was added as the project evolved, while other variables that were initially viewed as conceptually important – such as firm profitability, international engagement and ICT investment – have either been discarded or confined to sub-themes.

In addition to these two arguments, 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. But behind each observation in the plot, the DMD dataset contains a suite of variables ("indicators") 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.

Co-ordinated firm-level analysis

The project has conducted co-ordinated firm-level analysis of productivity and core ICT metrics, building on previous work and exploiting the development of comparable linked firm-level datasets. The rationale for this line of work is more pragmatic and opportunistic than the rationale for the DMD approach set out above. There is a natural interest in, say, the comparability of firm level relationships between ICT-usage and productivity across different countries, even if the "meaning" of these relationships is not thoroughly grounded in economic theory, and even if the relationships are not stable across countries.

An example is the employment effects of ICT adoption. Economic theory suggests there should be no such effects, but in practice this is an issue of interest to policy makers. In this regard we see the project as raising questions for further research, rather than providing all the answers.

3) Summary of Results

This section brings together analytical findings from the project. Results derive from the following different types of analytical work:

- at the most basic level, one-off studies of firm level productivity impact where only one country has data to perform specific analysis (eg work from Finland on ICT outsourcing).
- several 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, Sweden, Netherlands and UK on innovation).
- 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 and centrally written code to run identical regression analysis, for all countries except Denmark and Slovenia.
- construction of a 'metadata warehouse', used to weight and aggregate ICT use, structural business and business register data from surveys in all 13 countries in as comparable a way as possible, producing distributed microdata datasets (DMD); the aggregation process operates to produce estimates of complex indicators (constructed from more than one variable from a survey) as well as indicators which depend on intersections between surveys; this metadata system is also used to generate datasets on a highly comparable basis for firm level regression analysis within countries.
- industry / country level analysis of ICT impacts, using the large (and still under-explored) dataset produced by the distributed microdata (DMD) analysis system, where we have a highly comparable indicators, with the ability to draw reliable comparisons between industries /countries and over time.

Results from firm level analysis

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

- Project participants have completed analysis to show results relating ICT use at firm level to labour productivity from 11 of the 13 participating countries, on common metrics using an exactly comparable method, and using the common metadata to define and link variables.
- We know we can get results from the remaining countries with minor additional resources; the missing micro-data analysis is due to analytical resource constraints, or to limitations under which access to data was available for this particular project.
- Analysis of the properties of linked datasets in the project, using methodologies developed in earlier studies, shows that sample reweighting, using metadata and methods included in the project, is capable of dealing with most issues of 'representativeness' of data. This breaks down in cases where overlap between datasets is inadequate, and we have not advocated modelling in such cases.
- Linking of datasets in many countries, using 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 adequately to reflect small firms, sampling strategies would need to change.

Common firm level analysis across all NSIs

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

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, and reported in early work from this project are confirmed, in other countries participating in the project, productivity effects are insignificant or even, in one or two cases, negative.

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, or where there is greater market flexibility / dynamism, 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, and / or
- productivity gains requiring 'critical mass' in networks and ICT use, and / or
- measurement difficulties in services which are better tackled in some states.

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), but little or no separate impact of firm age.

Impact of ICT use metrics compared to IT capital measures

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 measures of ICT use over and above those of IT capital services in productivity models. The results show that impacts are 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 from 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'. Its impacts in different industries suggest different processes at work, which need to be understood in context, through different effects of information technology

(IT) and communications technology (CT). Impact analysis also needs to take account of ICT in combination with other factors such as skills and organisational change.

Fast growing firms

Analysis by INSEE shows that in France, the use of ICT does not affect the probability that a firm will show high growth characteristics (20% + employment growth over four successive years, not including firms with less than 30 employees). However, French microdata does show that intensity of ICT use for business purposes (% e-purchases or % e-sales, % employees with high speed internet connection) is a positive influence on the – small - probability that a particular firm will achieve high growth.

Validating these French results using the cross-country (DMD) datasets shows that high growth manufacturing firms are more intensive ICT users in a majority (but not all) of the countries covered, with intensity of electronic transactions appearing to provide the best indicator. Across the DMD dataset, fast growth firms in services in about half the countries are more intensive ICT users for business purposes – but not in the UK or France.

Employment, Skills and ICT Skills

Results from DMD analysis across Austria, Czech Republic, France, Germany, Great Britain, Italy, Netherlands, Norway and Sweden, for 26 sectors of manufacturing and services, show no clear relationship, at industry level, between ICT use metrics (internet and fast internet use by employees) and employment growth. Taken together with the results for fast growth firms above, this suggests that more intensive ICT use may increase the chances of growth at firm level, but this may be at the expense of competitors where industry effects are insignificant.

Three countries within the project, 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.

From all three countries it is clear that wages have a stronger correlation with productivity than do real measures of skills (this is partly an arithmetic effect as employee compensation is part of value added). The analysis shows that wages have strong 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.

Organisation / integration of e-business links, and ICT outsourcing

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
- the evidence in support of positive productivity impacts is growing.

However the exact form of correlation, and the channels through which productivity is linked, changes 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.

Graphical evidence from DMD analysis across Slovenia, Italy, Netherlands, UK, Czech Republic, Finland, Sweden, Austria, France and Norway shows, for most (but not all) countries, a positive relationship between position in national productivity ranking by quartile and %e-procurement in manufacturing, and for half the countries a similar relationship between productivity ranking and %e-sales in retail and distribution.

Regression analysis using firm-level data from UK, Netherlands, Sweden, France, Czech Republic, and Austria suggests, similarly, that productivity relationships are 'better behaved' for manufacturing, and that 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 links between processes within firms – suggesting that impacts through market dynamics are more important that efficiency gains through process coordination. The new ICT use survey (2007/8) will provide better,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 gains from more flexible work patterns);
- use of outsourced IT services (suggesting gains from specialisation).

IT Investment and ICT use

Evidence from Netherlands and UK, the two countries with firm level IT investment data (hardware only for Netherlands, hardware and purchased software for UK) shows that fast internet connected employees is, for the period, a good predictor of cumulative IT investment.

Evidence from both countries also suggests that the productivity effects of high speed communication used by workers are additional, over and above effects of measured IT investment, and so fast internet use by employees captures unmeasured inputs, knowledge management by employees, and more open, flexible methods of working.

In both countries' data there is evidence that the relationship between ICT investment and ICT use metrics differs across industries and countries, and that additional indicators (eg e-sales, and measures of business IT integration) may be significant; however the directional effects of the available ICT use metrics as indicators of IT investment are similar.

Given the difficulty (and cost) of collecting IT investment data at firm level experienced by most countries which have done it, the continued development of ICT use surveys as proxies for investment, and as indicators of IT impacts, is justified by this analysis.

Offshoring

For France, Sweden and Italy analysis has been conducted to explore the interaction between IT use and offshoring to test indications from earlier studies, and in the wider literature, that productivity advantages associated with globalised supply chains are reinforced by ICT use. Each of the studies uses a methodology which controls at firm level for 'IT maturity' by using a composite indicator from the ICT use survey. In all three the analysis is affected by the fact that offshoring firms are normally at the upper end of enterprise size, by employment.

Results for each country depend on data available. For France, where it is possible to test the relationship between labour productivity and an interaction between proportion of offshored intermediate goods and use of e-procurement, data suggest no cumulative effect. French results suggest that for manufacturing firms there are separate, significant, effects from importing intermediates from high wage economies (large) compared to importing from low wage economies (small).

French data also suggests that the observed productivity effects related to 'IT maturity' do not operate directly through mechanisms associated with offshoring. Swedish data show similar differentiated productivity effects of offshoring to high skill versus low skill countries, but the effects are visible for both manufacturing and service firms. However the offshoring effects are reduced in intensity and in significance by including IT maturity in the analysis.

Gains from offshoring by higher skilled Swedish firms (especially IT skills) are stronger where offshoring is to lower wage economies, suggesting gains from specialisation. The pattern of impacts for other combinations of industry / skill intensity / import source is more complex.

For Italy productivity effects of offshoring, after allowing for IT maturity, are sector dependent. For 'traditional' and 'scale intensive' industries the gains by offshoring to lower labour cost sources are significant; for specialist or science based firms, sourcing from high income countries is associated with higher productivity.

Our conclusion is that it is not yet possible to identify a cumulative effect of ICT use and offshoring of goods on firm productivity. If it were possible to extend the analysis in services the conclusion might differ. Difficulties in linking data are an important limitation to this analysis. The sampling strategies of most NSIs make it unlikely that a firm will be included in trade, ICT use and structural business surveys in the same year.

Innovation (using data from the Community Innovation Survey)

Survey overlaps limit analysis of relationships between ICT, innovation and productivity. However sufficient progress has been made by Sweden, Netherlands and the UK to draw some relatively strong conclusions 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 also is likely to reflect network effects on knowledge management, on the effectiveness with which firms are able to convert knowledge into new products and services, and on the speed with which they are able to commercialise them. The impact of e-commerce in Netherlands analysis may be evidence that marketing benefits of e-commerce for innovation (which research has missed up to now) 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 same tendency seen in the US by Brynjolfsson et al, for successful firms to be better able, and quicker, to replicate new market share winning innovations across production and distribution networks.

From Sweden and Netherlands there is initial evidence, using datasets restricted by the limits of overlap between production, ICT and innovation surveys, in regressions in which both effects are considered simultaneously, 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 limited the ability of other NSIs to contribute to the ICT / innovation analysis.

Results of Country / Industry analysis, using aggregated data

The project succeeded in applying the new metadata framework in all participating countries to produce comparable indicators. Results show that the statistical properties of overlap datasets between ICT use surveys and production surveys are sufficiently representative for the moments of the intersections set,to be used in analysis for almost all industries / countries. The project has shown that it is possible to use metadata to deliver useful indicators, including complex indicators drawing on and combining multiple responses within or between surveys.

A major limit on using this approach for wider analytical work, which needs to be tackled by Eurostat, is lack of an agreed approach to publication of aggregated data which, while not disclosive, is at a lower level than NSIs would normally publish. This is a problem for NSIs which are reluctant to see results placed in the public domain which may show unacceptable limits of error for individual estimates, and possibly conflict with official published data.

This problem explains why the report quotes little data from the DMD database built during the project, and that such data are quoted at a high level of aggregation. The industry / country level DMD data have been made available under conditions of confidentiality to analysts working within the project (within the European Statistical System) but under agreements made with NSIs the data is not generally available for research.

These issues of publication for more disaggregated data than NSIs are normally prepared to release are less relevant for cross sectional or growth accounting analysis. These use disaggregated data in ways that do not pose either disclosure or consistency problems to official statistics. Economists in the project team are keen to see this type of data used to broaden the scope of productivity analysis if the publication issues can be resolved.

Analysis on ICT indicators at industry / country level

Analysis across all countries in the study using standard National Accounts based treatment of productivity (as developed by EU KLEMS) shows worthwhile improvement in explanatory power, when carried out with ICT use indicators, constructed using the metadata to ensure comparability. This improvement is partly due to methodological differences in the treatment of ICT (especially software) in National Accounts, ICT metrics delivered by this project are more comparable both in source and in compilation.

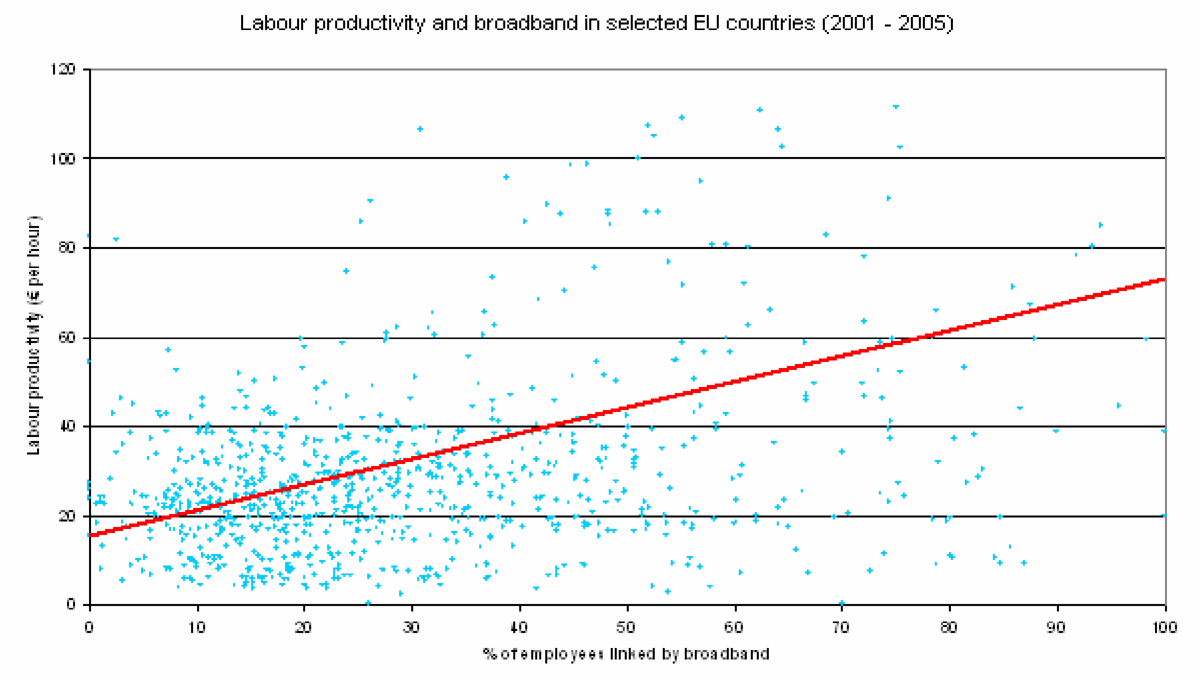


Figure 3

Source; Industry / country / year data from ICT use surveys and from EUKLEMS

High speed internet use by workers shows up in this cross country analysis as a more powerful indicator related to productivity than e-commerce measures, and as the most effective ICT explanatory input over the period 2000 – 2004/5 over which most of our international data are available. This relationship (Figure 3) is stronger at industry level than at firm level, due to reallocation effects within industries as more successful firms grow.

However, within country analysis of high speed internet suggests (as in the firm level analysis discussed earlier) that high speed internet use by employees is insignificant or negatively related to firm level labour productivity in Germany, Austria and Italy for 2001-2004.

After taking account of factors influencing adoption, both ICT adoption itself and the observed country / industry productivity effects are also positively associated with 'dynamism' of the market – i.e. the ability of ICT users to grow within their markets (and perhaps contribute to market expansion) and to take market share off less successful firms.

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.

The results of ICT use adoption models using this dataset seem consistent between countries, and the adoption rate is usually strongly associated with worker skills (measured by wages). Productivity regression equations are robust to inclusion of wages as a proxy for skills.

Initial analysis combining this work with 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 (measured using OECD's international framework).

4) Conclusions

The Distributed Microdata method

The project has demonstrated, by application in 13 different NSIs, that:

- linked micro-data can be used at the firm level for analysis of productivity effects associated with ICT and with complementary inputs;
- in all these countries it is possible to use a metadata framework to derive, for each national dataset, indicators based on linked data at industry level, and the results of this process can be used either as comparable indicators in their own right, or as inputs to cross-country productivity analysis along with other National Accounts based aggregates.
- The process for using linked surveys to produce industry level indicators can be operated without compromising disclosure practices in each country, and this should allow a useful extension of micro-data analysis across the EU (using ICT and other surveys), subject to appropriate institutional arrangements.

Earlier studies have shown that both IT investment and ICT use are linked to high productivity (in both level and change models). In this project, using indicators directly derived from ICT use surveys we show a positive correlation between productivity and the percentage of workers in an industry with access to (high speed) internet. These results remain, after controlling for ICT adoption. The evidence shows that countries or industries with a high proportion of skilled workers are more intense users of new technology. Further, the amount of variability in firm-level output growth across firms in an industry is seen to boost the intensity of firm use of internet.

A key ingredient missing from the statistical system, for policy analysts interested in productivity mechanisms, is direct evidence on how transactions are conducted in a market place. The underlying 'Keynesian' design of National Accounts has placed little importance on these intermediate transactions. The treatment of large parts of the economy as 'margins' (transport, trade, banking), rather than as creators of value and locations of technological progress is part of this problem. Measures of behaviour which can be integrated into National Accounts, as created here for the role of ICT, can play an important part in improving both the quality and the policy relevance of growth accounting and productivity analysis.

ICT impacts on economic performance

Our results show that the evolution of ICT and its effect on business behaviour and performance is an unfinished story. While productivity effects associated with ICT in manufacturing are becoming standardised across Europe, reflecting success in creating a single EU market and international value chains for goods, there is much less commonality in services. The reasons for these differences still require further investigation. Since services make up such a large part of EU economies this is a natural next step.

We have also seen evidence, in comparing this work to studies of ICT investment, that measurement of ICT capital formation (especially software) poses difficulties for National Accountants. These come both from differences in interpretation and implementation of OECD / UN guidelines for compiling software investment estimates, and from the difficulties in surveying 'intangible assets' such as software at firm level. These difficulties partly explain our results – and why ICT use metrics calculated using distributed microdata do a better job than National Accounts ICT investment metrics in explaining economic impact.

These observed difficulties do not mean that measurement of ICT capital is unnecessary. But the evidence from this study that measures of ICT use can be compiled and used in comparable analysis shows that alternative measures are available, against which ICT investment survey estimates can be benchmarked. Linked firm level comparisons for the UK and Netherlands, two countries for which firm level IT capital stock data exist, show that ICT use metrics (e.g. fast internet enabled employees) can provide a good proxy for IT investment.

A key conclusion is the relationship, in firm level data and in country / industry data, between productivity and fast internet enabled employees. In this sense, the i2010 objective of creating a 'single European information space' can be tracked, in economic terms, by the proportion of fast internet enabled workers. The productivity effect depends not only on this variable's role as a proxy for IT capital, but also because it represents working practices of employees, investment in business processes, knowledge management and organisational capital.

It looks probable – since 'fast internet enabled workers' does not yet show as a productivity driver in service industries in less ICT intensive countries - that it will remain a useful metric for some time to come. The split of four broad industries used in our analysis (ICT goods and services producing industries, non-ICT manufacturing, distribution and non-ICT services) is consistent with the KLEMS classification and also looks to be a useful analytical approach for ICT indicators, given the different results we see between them.

E-commerce (sales and purchases) and e-business links within and between firms also show productivity impacts, with effects of e-sales and e-purchases that are consistent with earlier work, and reflect changes in business behaviour. We have also seen that productivity impacts can be associated with e-business process links, especially between firms, but an effective way to model this must await more extensive data available from the 2007/8 Eurostat survey. It is probable that these will remain useful indicators of change in behaviour and performance.

The most significant set of results from firm level analysis are the relationships from the three countries which have linked innovation and ICT use surveys. These suggest that much of of the productivity impact associated with ICT investment and use is through innovation, including non-technical and business process innovation, through a range of mechanisms:

- by enabling knowledge exchange and management, through networks,;
- by supporting 'roll out' of new goods, services and processes, through ICT enabled business systems which enable rapid scaling up and replication;
- by enabling better marketing of new products / services to new markets via e-commerce;
- by 'being the innovation' in business process improvement and redesign.

This evidence should be considered alongside the growing literature on 'innovation accounting', developing at both firm and national accounts level. This recognises a range of intangible inputs to innovation, including software, technology based R&D, non-technical expenditure on new products and services, skills, organisational and reputation capital. The framework is still under development with major measurement problems especially in the areas of non-technical service innovation (not least financial services) and organisational and business process change. But the role of information and organisation in the 'intangibles' framework suggests that ICT hardware and software are central to its infrastructure.

Looking ahead to a 'next generation' of ICT impact indicators, the changing patterns of innovation should perhaps be an organising framework for thinking about how measures should develop. The interaction between ICT as a knowledge management infrastructure, and the skills (ICT and general) of workers is worth further exploration. So to is the relationship between ICT and organisational / business process change or 're-engineering'.

Limited statistical work has been done so far on measuring the increasingly complex use of ICT to manage customer relationships and user input to innovation by firms, in user driven or 'open innovation'. However, the arguments above suggest that it should be on the agenda for future investigation of the ICT – innovation links. In the recommendations below we make a number of suggestions on how these links could feature in future surveys.

5) Recommendations from the study

For Analysis

1. The project has shown that distributed micro-data analysis works, that it can be extended to new countries with investment in metadata and analytical capacit, and some central coordination, and that this approach can be used to develop effectively comparable ICT use indicators across countries / industries, using existing sources. We recommend this process, based on pooling detailed survey metadata from each country is extended to as many other countries as are willing to use the model. This could be coordinated by Eurostat, or, with Eurostat support, by the expert group created in this project.

2. The project has shown that new indicators, or new formulations of indicators to reflect interest in specific industries or firm types, can be generated by country / industry across the EU quite quickly, using existing surveys if the necessary metadata structure is put in place in advance. This provides a more flexible approach to indicator development and adaptation than the current Information Society Statistics regulation, and should be considered as a useful addition to the IIS regulation.

3. In order to conduct distributed micro-data analysis it is necessary to link ICT use surveys with production surveys. Therefore there is a good case for building up the metadata structure covering the ICT use survey (which is relatively easy as all countries undertake a similar survey), and as an absolute *minimum, metadata for those parts of the production surveys and administrative data systems which help to weight linked surveys for industry level analysis. Developing the metadata structure to include all those areas of the production surveys and business registers used in this study (see Table 4.1, Chapter 4), would be the best option, and is recommended.*

*4. Linking through the metadata approach should be done between ICT and innovation surveys, to test the models developed in this project across the few countries where linking is already practical. These suggest that ICT is central to parts of the innovation cycle. More extensive analysis of the relationship between ICT use in firms and steps in the innovation process, broadly defined to include non-technical innovation, would improve understanding of key elements in the working of ICT impacts. We recommend that this should form part of a further, limited, study. Much groundwork for this has already been done by OECD's Working Party on Industry Analysis***.**

*5. The analysis has shown that for those countries where data on firm level IT investment are available, as well as ICT 'intensity of use' indicators, there is a strong relationship between them. Some of these indicators are good proxies for IT investment as measured directly in surveys, and ICT use measures also proxy relatively well for the effects of IT/ CT and other forms of complementary investments. In part this is because firm surveys find it hard to capture some elements of IT spending (especially own account), and therefore use surveys may give more reliable indicators of ICT intensity. We recommend that these conclusions be taken into account in assessing the value, frequency and priority of firm level IT investment surveys***.**

6. The analysis of productivity effects of ICT, at both firm and industry level, has tended to confirm the view that impacts for ICT can best be measured through ICT in use (i.e. measures of what, and how much, firms do with ICT) rather than ownership measures of ICT assets. Such measures are preferred, in terms of explanatory power, to less effective statistics on ICT investment, in part because of the difficulty of measuring different elements of ICT capital. We recommend that in developing analytical frameworks for impact assessment this principle – that what matters is what and how much, firms do with IT, rather than whether they have it, is given priority.

7. Frameworks for assessing impacts for ICT should recognise the different roles that ICT plays in the different stages of the innovation process Especially in service firms, hardware, software and communications systems determine the adoption of new work practices and knowledge management systems, and may embody changes in business processes. We recommend that analytical frameworks for further indicator development should explore these areas in greater depth than we have been able to. The evidence from this project would justify further analysis, supported by new survey data if possible, on the role of ICT in, and between, firms as:

- *infrastructure for knowledge gathering from outside;*
- *the basis for knowledge management and diffusion within the firm;*
- *the central element in commercialising new goods, services and processes and replicating them within and beyond the firm;*
- *the key driver of business process change, combining with complementary intangible investment to enable productivity improvements directly.*

For Surveys

1. Current surveys on which we have based this project are designed for existing 'single survey' compilation of ICT penetration and use aggregates. Few NSIs have yet designed ICT use surveys specifically to make the most of microdata analysis based on data linking, although all are conducted *using business registers which permit linking. Also, within the European Statistical System ICT use surveys and Innovation surveys have grown up separately, which may make them more difficult to link, because of differences in some countries in business reporting unit definition. Given the conclusions reached in analysis for countries where the two can be linked we recommend that further thought be given to examine the way ICT use and innovation surveys are done in order to improve the links between data sets. The options available might include*

- *an 'innovation module' in the next available ICT use survey to investigate how firms have used ICTs to change their products, services and processes, rather than a focus on 'static' questions about what business process links they use ICT for, as in the current survey;*
- *redesigning the ICT use and innovation surveys so they work better as complementary surveys, with linkable questions on how ICT is used to develop new products, services and processes, both in technology based and in non-technological innovation, including new organisational and business process developments;*
- *converge the two surveys, with less emphasis on ICT questions asking about specific technology and more emphasis on asking how ICT use changes firm behaviour, employee behaviour and the relationships with suppliers / customers (although merging surveys could lose valuable information);*
- *include in both surveys questions that facilitate analysis toward the interrelationship between intensity of ICT and degree, and model, of innovation. This would preserve the advantages of each survey, but at the possible cost of additional compliance burden on respondent firms.*

Careful thought will need to be given in survey development to the fact that ICT and innovation surveys are currently answered, in many firms, by different respondents, and require different knowledge. This is a strong argument for keeping the surveys separate, and starting future investigation with an 'innovation module' in the ICT survey. However, some of the innovation issues, on organisation and business processes, may well be accessible to ICT managers as easily as R&D managers who tend to answer current innovation surveys.

2. The recommendation above would improve understanding of the process of innovation in services, which is often organisational rather than technological, and enable us to get over the current 'two survey limit' which in most countries makes it very difficult to assemble a sample for analysis of ICT, innovation and business performance in any but the largest firms. This constraint needs to be overcome for effective analysis on larger numbers of firms, or for focusing on specific business types. The new questions on data exchange and on electronic supply chain management in the model 2008/9 survey could provide a base from which such questions could be developed.

3. An innovation module would also build understanding of the relationships between ICT, innovation and business performance in smaller firms, where the current sampling and survey structure gives very little data to analyse. The analysis in this project has done enough to show that the innovation and productivity effects of ICT differ between broad business types – and are reasonably common in manufacturing firms across all 13 countries. We recommend that developing better data to support analysis for services (often comprising smaller firms) should be a priority as the ICT survey develops.

4. We recommend that consideration is given to asking about how, and how intensively ICTs are used to acquire and manage knowledge, to develop and commercialise new products and processes. Existing data in a few countries are adequate to suggest links between ICT and the innovation process. However, there are questions which the Eurostat common survey does not currently ask about issues such as co-innovation through information exchange, ICT to support flexible working arrangements, *and ICT to aid outsourcing, which could be interesting as impact indicators. In those countries which do ask such questions they turn out to be significant as determinants of business performance.*

5. We recommend that Eurostat should consider paying equal attention in survey and sample design to generating aggregates in ICT use surveys (which currently dominates survey specifications), and to the design of surveys to support the exploitation of microdata for impact analysis (today not considered at all), which focuses on differences between respondents in a survey, and which often depends on intersection of linked surveys. This change would affect questionnaire design, sampling and the use of panels. In development of the Community Innovation Survey in a number of countries more attention is now being given to building panel datasets, to support better analysis of technology adoption and its impact on firms over time. Similar attention in ICT use surveys would be useful, especially for smaller firms where panel elements in existing surveys are very small.

For Indicators

1. The project has produced a 'complex' indicator[1], using two elements of the ICT use survey which is strongly linked to productivity at firm or industry level for this decade. The 'fast internet enabled employees' metric is a proxy, in economic terms, for the 'common European information space' over the last five years – and for some time ahead. It has greatest impact in more knowledge intensive industries, and is linked, in analysis, to the innovation process.

2. It has also produced clear evidence of links between ICT intensity in EU industries and countries, and competitive dynamics. In more ICT intensive industries (measured by use) the tendency of firms to gain or lose market share is larger. There is also evidence that the combination of more dynamic markets (entry / exit / innovation) and ICT use is complementary for productivity improvement. Complex indicators which bring these two together will be worth considering.

3. Complex indicators representing the complementary use of ICT, and engagement in innovation (technological, organisational, or other), would also be worth considering on the basis of evidence from the study. This would require the CIS survey to be added to the metadata framework. The relationship between skills and ICT could be one candidate for a complex indicator, either through CIS linking (using CIS higher education questions) or using the ICT skills data from the 2007 model survey to test ICT use / skills complementary effects on productivity

4. In our analysis we have shown that greater intensity of ICT use (on various measures) is related to other metrics of 'business change' - in the broadest sense defined by the innovation survey, and that at least some of the productivity gain attributed to ICT investment and use can be traced back to ICT through innovation. If this conclusion is right, and policymakers need indicators to help explain changes taking place in firms, and across industries, then it makes sense to look for measures which relate to the main sources of competitive growth. In this study we have shown evidence for several such indicators, and suggested a framework which relates ICT indicators to sources of growth. A summary is shown in Appendix 2.

5. The NESIS project in 2004 recommended greater use of intensity indicators, some of which have been developed in Eurostat surveys. This study has shown that 'use intensity' indicators using existing surveys are more effective indicators of ICT impact than simple 'possession' or 'expenditure' metrics. Developing the conclusions of both these studies, we can suggest future benchmark indicators, some of which could be developed from Eurostat surveys in the pipeline, while others will require new survey questions, or recasting of the relationships between ICT use and other surveys to permit more extensive *linking. Suggestions include attempting to gather information on firm spending on complementary investment to ICT, which has been successfully tried by industry experts in the UK.*

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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

Appendix 2: Indicators in the project using existing data, and suggestions for the future

A : Framework for 'sources of growth' which can be described using existing surveys

Firm level	
Source of growth	**Possible role of ICT**
Acquisition of knowledge from outside the firm	Internet links to professional experts, 'customer driven' idea generation
Managing knowledge to formulate commercial ideas	Internal networks between people
Turning ideas to delivered products / services	Replicating product / service through ICT based 'enterprise architecture'
Marketing to target customers	Use of CRM systems, or web marketing
Industry / economy level	
Source of growth	**Possible role of ICT**
Faster spillovers of knowledge between firms	Industry levels of internet exchanges
More efficient markets, speeding up reallocation	e-commerce penetration
Supply chain management / optimisation	e-procurement

B : Indicators which can contribute as impact measures, related to sources of growth

Measure / indicator	**Element of growth contribution**
From existing data	
Fast internet enabled employees, by firm and industry % e-sales, by firm and by industry % e-procurement, by firm and by industry ICT investment / employee use Dynamism (share change) in high ICT using industries	ICT investment, knowledge acquisition and management Marketing efficiencies / targeting Supply chain management, market efficiencies Enterprise architecture, to replicate processes Speed of reallocation of resources
From data in the 2007/8 and 2008/9 surveys	
ICT skills and ICT use in firms Summation of e-business links Intensity / extent of information sharing (from 2008/9 survey)	Ability to absorb and manage knowledge Internal / external business systems, and ability to replicate new products / processes Internal / external coordination, and ability to replicate new products / processes
From survey extension / better linking	
Skills and ICT overall capability - needing a linkable skills question Investments complementary to ICT, requiring some form of expenditure question (e.g. how much spent on process redesign compared to ICT)	Absorptive capacity of firm for new ideas Training, business process change etc; how much firms invest in 'business change'