The Role Played by ICT Human Capital in Firm Productivity

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Abstract

This paper broadens the research perspective on how information and communication technology (ICT) relates to firm performance by studying the productivity effects of increases in the proportion of ICT intensive human capital, an often neglected intangible input. The effects will be investigated both on their own and together with the impact of the firm ICT maturity.

Starting from a relaxed Cobb Douglas specification and by means of the OLS we estimate the influences on firm productivity for a group of five European countries using the unique *ESSnet on Linking of Microdata on ICT Usage Project* panel dataset including the years 2001-2009. The results give that increases in the proportion of ICT intensive human capital does indeed boost productivity, generally far more than ICT maturity. However, the gains vary somewhat across countries and industries and the channels through which the effects operate might be narrower for the ICT intensive human capital than for skilled human capital on average.

JEL codes: D22, D24, L810, I210

Key words: firm productivity, human capital, information technology

*The views expressed in this paper are purely those of the authors and may not in any circumstances be regarded as stating an official position of the European Commission or Statistics Sweden. The results presented are based on own calculations on the datasets available within the ESSnet on Linking of Microdata on ICT Usage Project and should not be confused with official statistics.

Introduction

This paper broadens the research perspective on how information and communication technology (ICT) relates to firm performance by studying the productivity effects of increases in the proportion of ICT intensive human capital, an often neglected intangible input.

Much has happened since Solow (1956) in his neoclassical reasoning recognised technological change as an important factor of growth and then later in a (1987) New York Times book review exclaimed that *you can see the computer age everywhere but in the productivity statistics*. With this he meant that the technological revolution that many felt they had experienced was not accompanied by a growth in productivity, but rather the reverse. There could of course lay many reasons behind this. Economic literature suggests two main explanations to the "Solow paradox". One of them is that the economy as a whole and its human capital may need additional time and effort to adjust to new technologies. Another is that data detailed enough for proper studies might not have been available. An important inference from literature on productivity gains from ICT as an enabling technology also implies that complementary investments are necessary to achieve an efficient allocation of production resources.

Traditional macroeconomic measurement framework is not perfectly tuned to fully capture the specificity of enabling technologies as an input to production and would typically underestimate returns from ICT. On the surface, this results in seeing computers "everywhere but in the productivity statistics". According to Brynjolfsson and Hitt (2000), total capital stock associated with computerization of the economy may be understated by a factor of 10. This bias is mainly due to difficulty to adequately describe and measure the mechanisms by which firm-level returns sum up to the industry- or economy-wide benefits, and to account for enabling complementary factors.

In the last decade several studies addressed the above shortcoming of the macroeconomic approach by going beyond a traditional growth accounting method and by applying the firm-level analysis (see Brynjolfsson and Hitt, 2000 for a detailed literature review). These studies suggest that the productivity performance at the macro-level has its roots in many years of computer-enabled organizational adjustments undertaken at the firm-level, and has a lot to do with large investments in intangible assets. Studies that encompass the effects of different kinds of investments in ICT on both aggregate and disaggregate economic performance are well-established: Draca et al (2006) sum up a wide range of micro- and macro literature on productivity effects from information technology both from the growth accounting and the econometrics standpoint.

Firm-level analysis has significant measurement advantages for examining intangible organizational investments, and product and services innovations associated with computers and how they are used or connected. While going down to the firm-level statistical evidence helps to control for many biases that result from aggregation, it is often difficult to find a good quality data representative for the whole economy, letting alone a multi-country panel. Such data for the United States was explored by Brynjolfsson and Hitt (1995) and Lichtenberg (1993). For Europe, the most informative data with regard to ICT-led productivity gains is the one collected by the Eurostat ICT impacts projects. This data were explored by among others van Leeuwen (2008) and Bartelsman (2008), who found that ICT investments as well as ICT maturity, approximated by usage, boosted productivity. Based both on the theoretical reasoning and on the empirical evidence, part of productivity gains can be thus thought to be derived from the organizational capital (Caroli and Van Reenen 2001, Brynjolfsson et al, 2002, Brynjolfsson and Hitt, 2003, Bloom, Sadun, and Van Reenen 2005) and to be conditional on unmeasured complementary factors, with the human capital being the most important one.

Despite the fact that human capital has been in the focus of productivity studies for many years, and that the issue of how and to what extent higher education affects growth is often high on the political agendas, the role played by *different kinds* of human capital is very often left outside the research lens. However, some studies, by for instance Niringiye et al (2010), Rao et al (2002), Iranzo et al (2008) and Black and Lynch (1996) points at the importance of skilled labour for increases of firm productivity and that type of skill may be crucial too, even if they do not investigate the effects of ICT skills in particular. Bartel et al (2007) find that ICT could affect all stages of production and may also change the demand for labour, which could be seen as an indicator of the importance of specific skills for the firm performance.

Ilmakunnas and Maliranta (2005) comes closer to the type of skills when they show that non-technical education affected firm productivity positively and stronger than technical ones in Finland. Similarly, Hagsten and Kotnik (2008) show that ICT intensive human capital may affect firm performance, and under certain circumstances differently from the generally skilled, meanwhile Gunnarsson et al (2001, 2004) find that an upgrade in the skills level with constant technology affected the firm performance more than the other way around. They also found that ICT in the shape of investments was complementary to skills. This follows the reasoning by Acemoglu (1998) about technological change in general, and about ICT being a complement rather than a substitute to skills, in particular. Forth and Mason (2004) make distinction between skills necessary to the ICT adoption and to the ICT utilization and investigate the impact of skill constraints on firm-level performance. They found that reported ICT skill deficiencies at firm level restrict the adoption of ICT, and limit the benefits which are gained from using ICT once required investments have been made.

In this paper we suggest a framework that captures several nuances associated with the specific nature of ICT as a general purpose technology in its relation to productivity. Our approach sheds light on the productivity contribution of ICT that is often left beyond economic analysis and may typically lead to underestimation of its returns. In doing so, we explore the unique *ESSnet on Linking of Microdata on ICT usage Project* data set and report results of several extensions to the previous work aimed at providing contributions to the resolution of the Solow paradox. We pose and attempt to answer the following research questions:

Firstly, we measure the presence of the intangible complementarities derived from the nature of human capital employed in production, in particular by discriminating between generally skilled and the ICT intensive human capital. Secondly, we test for the productivity effect of the ICT-enabled organizational adjustments that are undertaken at the firm-level and that are mainly related to investments in intangible assets. We capture these organizational adjustments by the ICT maturity of a firm. Thirdly, we distinguish between the productivity effects of two groups of firms with different production processes such as manufacturing and services. And finally, we analyse all above mentioned productivity effects separately for five European countries – Finland, France, Norway, Sweden and the United Kingdom – and report the evidence of important cross country difference in the use of ICT and in its impact on firm productivity that can be partially attributed to the variety of country-specific channels by which ICT investments are transmitted into productivity gains (related, for example, to the structure of the economy, specific modes of ICT application, availability of skilled human capital, and management practices).

Method

Following the mainstream literature based on the economic theory of production, we assume that firms produce a homogeneous product, and use the Cobb-Douglass specification as the first approximation of the arbitrary production function. In our case, when more than two production inputs are considered, a more general functional form such as transcendental logarithmic (translog) production function would be more suitable compared to the more restrictive Cobb-Douglass specification (Christensen et al., 1973). However, Brynjolfsson and Hitt (1995) found no significant difference in the contribution of ICT when the restrictiveness of using a Cobb-Douglas specification is relaxed. Similar to other microdata studies by for instance Ilmakunnas and Maliranta (2005), and Black and Lynch (1996), the firm output can be expressed as

$$Y = f(A, K, L) = AK^{\alpha} L^{\beta} \tag{1}$$

where (A) is the constant technology, (K) is capital and (L) is labour. Coefficients ($\propto$) and (β) are the output elasticities of each input with a given technology, and the assumption of constant return to scale over time sum them both up to one. This means that a change in the inputs affects the output proportionally. The partial output elasticity of the production function measures the per cent change in production from an increase by one unit of the input in question.

Transformed into a log-linear function, production can be then specified for each firm i at time t where (lnA) is the coefficient of productivity and ε_{it} is the error term. This transformation of non-linear variables permits the use of linear estimators like the OLS. The linearization also facilitates separate analyses of the parameter estimates.

$$lnY_{it} = lnA + \propto \ln K_{it} + \beta lnL_{it} + \varepsilon_{it} \quad (2)$$

Some additional considerations are required if we want to model ICT as a production input. If ICT is primarily an investment good (as in, for example, Farooqui and Van Leeuwen, 2008), it may affect productivity not only as a production input but also by changing the production function itself and by stimulating and enabling complementary innovations. Moreover, as advocated in various works by Bresnahan and Trajtenberg, Carlaw and Lipsey, and Brynjolfsson and co-authors[1], it is an investment of a special kind, a general purpose technology. The productivity impact of the general purpose technologies is known to be substantially larger than would be predicted by considering the quantity of capital investment in combination with a normal rate of return. The output elasticity of ICT as an input into production can be thus greater than its input share, indicating the excess returns on computer capital stock or on ICT-specific labour.

In order to account for various productivity effects derived from the use of ICT we have chosen to depart from conventional productivity studies that test for direct effect of ICT investment, and to decompose this effect into a set of different control variables as described below. We assume two types of technology effects, each of which may be related to the ICT but is materialized through different types of channels. Let us assume that the first type of technology effects captures the productivity shocks at the aggregate (country and industry) level, while the second type can vary at the firm level. These effects are often jointly called a multifactor productivity and in most of studies the clear distinction between them is absent.

Aggregate productivity shocks (d^f) can be identified by two dummy variables, one capturing the productivity effects specific to the industry, in which the firms operates, and another capturing the time-specific variations in productivity. Thus, by holding industry and time effects fixed, we account for short run productivity shocks within each industry and longer run disembodied technical change at the country level.

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[1] See, for example Bresnahan and Trajtenberg (1995), Carlaw and Lipsey (2006), Brynjolfssonand Hitt (2000), Brynjolfsson et al (2002).

Similarly to Bartelsman and Wolf (2009) we assume that there exist a *firm-specific productivity shock* (δ) unobservable for the econometrician but known to the firm (at least up to its expected value). By allowing for the cross-firm variation in δ we should be able to correct the omitted variable bias by accounting for the fact that some firms can be persistently more productive than others due to their *firm-specific organizational capital*. Such organizational capital determines the ways by which ICT assets are transmitted into the productivity gains at the firm level. Thus, we assume that firm's decisions regarding investment in ICT real or human capital are conditional on the unmeasured productivity-enhancing characteristics (such as, for example, management skills or expertise and experience in operating the ICT technologies). Failing to account for these effects will lead to an imprecise estimation of the productivity impact of other inputs.

There are several ways to go round this type of omitted variable bias. The most straightforward approach is to introduce a firm-specific dummy variable and to estimate the productivity equation by the OLS technique. However, this is not feasible due to the large sample of firms in our panel. Alternatively, following Brynjolfsson and Hitt (1995), we can apply a linear "within" transformation of the equation that eliminates the firm-specific effect but leaves all other coefficients unchanged. This technique removes the firm-specific intercept term from the regression. Brynjolfsson and Hitt (1995) found that elasticities of ICT inputs (capital and labour) drop by roughly half when controlling for within (firm-specific) effects, while elasticities of other inputs are not significantly affected. However, Ilmakunnas and Maliranta (2005) find that the within estimator risk to wipe out too much of the data variation and assumed that their vintage variable (firm age) captures the unobserved effects, at least to some extent.

In this paper we use the third way to control for a firm-specific productivity effect by introducing a set of variables that jointly characterise firm-specific organizational capital. One such variable is ICT maturity (x). We assume that higher ICT maturity translates into more effective investment decisions with regards to ICT capital and labour. To our knowledge, no studies have used this variable in this context so far. Another set is the vintage variables (z), which we include because firm age itself may be of importance for productivity and age squared could inform on a possible non-linear relationship. Additionally, we introduce dummy variables controlling for firm characteristics, (d^c). In earlier studies by, for instance, Criscuolo et al (2008) it was found that larger firms tend to operate on higher productivity levels. Being internationally active or affiliated has also been proved to affect productivity. Based on this reasoning, we control for such firm characteristics as size, international experience and affiliation.

We further assume that differentiation between types of human capital allows testing for distinct productivity gains. To this end, we distinguish between skilled labour – *ICT intensive human capital* and *general human capital*. By ICT intensive human capital we do not mean the general level of ICT literacy, which becomes increasingly essential at virtually all stages of production and distribution, is often acquired through learning-by-doing and, as a rule, is resistant to measurement. Instead, we refer to the deep knowledge of ICT technologies, officially certified by educational credentials. We believe that these specific skills are related to effectuation of comparative advantages in operating information technologies and in stimulating and enabling complementary innovations.

Thus, the channels through which human capital is expected to affect productivity can be described in a fashion similar to Durbin (2004): through the more able highly skilled employees who can work better, make better use of other inputs of production as well as take part in knowledge spillovers to their colleagues. This means that the impact on productivity could be either direct or indirect, but it does not necessarily mean that all kinds of firms gain from similar types of human capital. Nor does ICT intensive human capital necessarily translates into productivity boosts instantaneously and ceteris paribus, but rather through a more exact match with industry and tasks.

Including all above described control variables, and representing coefficients as betas, we can write the estimation equation for labour productivity as

$$lny_{it} = \beta_0 + \beta_1 \ln k_{it} + \beta_2 \ln l_{it} + \beta_3 ln\boldsymbol{s}_{it}^{l} + \beta_4 \boldsymbol{x}_{it} + \beta_5 \boldsymbol{z}_{\boldsymbol{it}} + \beta_6 \boldsymbol{d}^{c} + \beta_7 \boldsymbol{d}^{f} + \varepsilon_{it} \quad (3)$$

where ε_{it} constitutes the stochastic term assumed to represent nothing more than white noise.[2]

In order to investigate whether the human capital affects productivity stronger on its own or as a complement to ICT, as suggested by Acemoglu (1998), an interaction variable can be created. We introduce an interaction term similarly to Gunnarsson et al (2004), but use the ICT usage instead of the ICT investments.

We first estimate equation (3) directly for the whole sample, thus constraining the labour productivity effects to be the same across all firms. We then target the two distinct sub-samples, manufacturing and services, which allows estimating the coefficients specific to these sectors.

Descriptive data

The data used in this analysis originate from the national and cross-country sets built up within the frame of the two *Eurostat ICT Impacts* and *ESSnet on Linking of Microdata on ICT Usage* projects.[3] These datasets in turn mainly consist of information collected from the business registers, the production surveys, the EU-harmonised firm ICT usage surveys, the community innovation surveys and to some extent other registers.

Because the access to data on individuals and firms is restricted in most countries, a way to work around this was needed. The tool used for that is a method called *Distributed Micro Data,* described by Bartelsman and Barnes (2001) and Bartelsman (2004), implying that identical analyses are conducted separately on national firm level datasets. The resulting indicators and estimates are then aggregated to a level where disclosure becomes less of a problem and fed into the cross country dataset for further exploration. This method relies heavily on careful initial analyses of metadata in order to assure comparability of the data used. In practice it means that similar codes are run on each national dataset, including modules for different analytical purposes like indicators and regressions.

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[2] Since s^l and u^l comprise the sum of skilled and unskilled employees, only one of them needs to be included in the estimations.

[3] Eurostat Grant agreements 49102.2005.017-2006.128 and 5070.2010.001-2010.578.

Table 1. Number of firms and sample overlaps

2009	FI	FR	NO	SE	UK
Production survey (PS)	133723	39841	271711	701033	41528
ICT usage survey (EC)	2938	9389	4041	3166	5218
Linked PSEC	2924	9389	3897	3166	2071

Source: ESSnet on Linking of Microdata on ICT Usage Project Cross Country Dataset

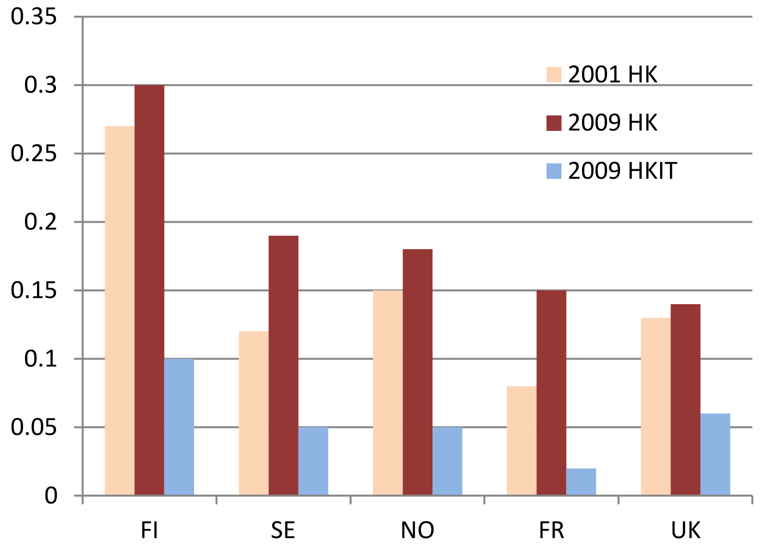
The production surveys (PS) are large in all countries, although they are not always register based like in the Nordic region, but nonetheless aimed at being representative. However, for several reasons different samples may lack coordination with each other (small or non-existing overlaps). Easing the response burden of firms is one of the reasons behind that, unfortunately this can lead to a certain selection bias, meaning that the extent to which general conclusions can be drawn from analyses on such datasets are not completely clear. In the group of countries studied here, the linking of the datasets only lead to marginal losses of observations in the ICT usage survey (EC), which is a guarantee of representativity. Nevertheless, a certain concern could be raised over the small overlap in the United Kingdom dataset, which might imply a more apparent bias towards larger firms than in the other countries, given that it is not derived from none-responses, in which case the bias is unknown. Since there is a certain amount of exit and entry by the firms over time and because only a smaller subset of firms, the largest ones, will appear in the sample each year, the matched datasets will be kept unbalanced.

Data on educational achievements are not always available at firm level, so although the project consists of 15 European countries, for the time being only five can provide the information required on human capital. In Finland, Norway and Sweden this is based on register data meanwhile the United Kingdom uses the Community Innovation Survey and France derives the information from its occupation register.

Educational attainment is strictly formally based and not influenced by the production values, and will of course fail to encompass skills from learning by doing. A proxy including wages might have been able to capture also informal skills. However, the general lack of analyses based on formal educational achievements makes this angle more intriguing. The problem of wages being closely related to the production values is also avoided by this approach.

Diagram 1. Proportion of employees with post upper secondary education

Per cent



Note: Finnish data refer to the years 2001 and 2008. HKIT means ICT intensive post upper secondary education and HK includes all degrees.
Source: ESSnet on Linking of Microdata on ICT Usage Project Cross Country Dataset

ICT intensive human capital is equalised with post upper secondary education in mathematics, physics, engineering or information technology based on two-digit international ISCED-codes (International Standard Classification of Education). The proportion of employees with this education is quite low everywhere except in Finland, meanwhile the proportions are far larger for generally skilled human capital (Diagram 1).

Table 2. Highly skilled human capital by industry

2001 2009 PS		FI		FR		NO		SE		UK	
		2001	2009	*2001*	2009	*2001*	2009	*2001*	2009	*2001*	2009
Employees with ICT intensive post upper secondary education, per cent	All firms	*10*	10	*1*	3	*3*	4	*3*	5	*5*	6
	Manufacturing	*10*	12	*0*	2	*2*	2	*2*	3	*5*	5
	Services	*10*	11	*1*	4	*4*	5	*3*	7	*5*	6
Employees with general post upper secondary education, per cent	All firms	*17*	19	*8*	12	*12*	18	*9*	15	*8*	9
	Manufacturing	*10*	12	*8*	12	*8*	11	*6*	7	*5*	6
	Services	*22*	24	*7*	15	*15*	18	*9*	16	*11*	10

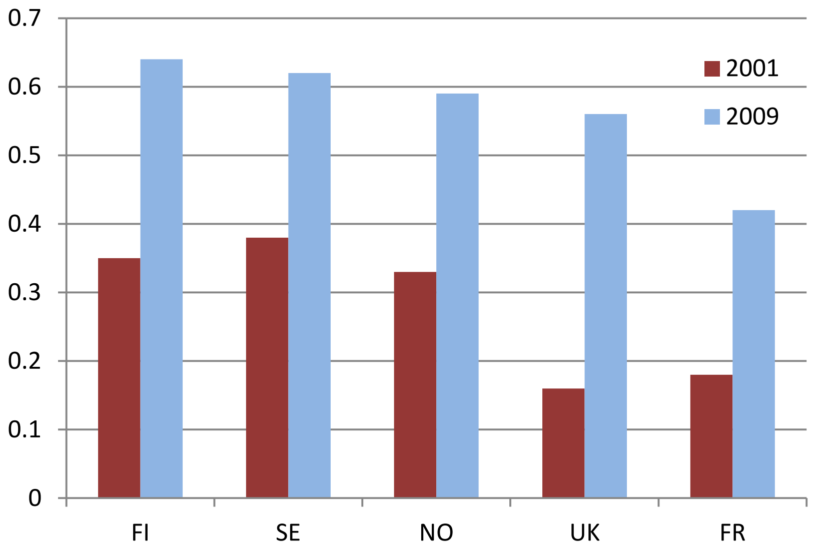
Note: Finish data refers to the years 2001 and 2008.
Source: ESSnet on Linking of Microdata on ICT Usage Project Cross Country Dataset

The uptake of graduated employees has improved over time and the services firms seem to be the ones that make most use of highly skilled employees. Table 2 reposts the general and ICT-specific human capital endowment for all firms in country-specific samples and for the manufacturing and services firms separately. The financial firms are not reported alone due to small samples.

Finland has the highest proportion of broadband Internet enabled employees, closely followed by Sweden who was the lead user in the early 00s (Diagram 2). Both Norway and the UK remain in the vicinity, but France is lagging behind somewhat. This latter role was earlier held by the UK. Finland is also far ahead of the others in its use of mobile connections, with Sweden on a clear second place.

Diagram 2. Broadband Internet enabled employees

Per cent



Source: ESSnet on Linking of Microdata on ICT Usage Project Cross Country Dataset

As opposed to the degree of broadband Internet enabled employees, which seems to be far more frequent among services firms, the mobile connections hardly differ at all between the two groups of industries (Table 3). The willingness to early adoption and the high level of ICT maturity in the Nordic countries could well be related to geographical conditions. In sparsely populate areas a high level of ICT usage may increase the job opportunities and facilitate the efficiency in the labour market, meanwhile in more densely populated areas measures to increase firm efficiency may solely be seen as threats against the jobs.

Table 3. Firm ICT maturity

2009 PSEC		FI	FR	NO	SE	UK
Proportion of Broadband Internet enabled employees, per cent	All firms	64	42	59	62	56
	Manufacturing	51	38	52	54	44
	Services	75	48	67	69	62
Proportion of firms with mobile connections, per cent	All firms	81	59	62	68	62
	Manufacturing	82	56	63	68	61
	Services	81	61	60	68	62

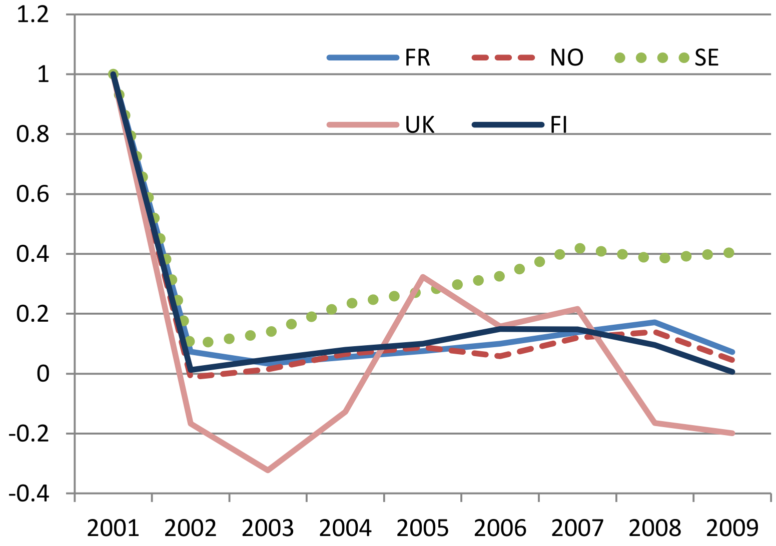
Source: ESSnet on Linking of Microdata on ICT Usage Project Cross Country Dataset

Despite many similarities, the industry structure in the countries investigated still shows some differences. Apart from the oil industry Norway is also heavy on retail trade and transportation. Retail trade is common in the UK and France too; meanwhile Sweden has high activities in construction and wholesale. All countries have vast numbers of employees within the business services sector.

Beyond the difference among industries, those firms intensive in skilled human capital, either ICT or general, on average and independently of country, do have more employees with access at work to broadband Internet or mobile connections. These same firms are also most often high in capital, wages and productivity, just like the findings by Doms et al (1997), Durbin (2004) and Galindo-Rueda and Haskel (2005).

Diagram 3. Growth of labour productivity

Per cent



Note: Labour productivity based on value added, re-weighted with respect to sample size and number of employees.
Source: ESSnet on Linking of Microdata on ICT Usage Project Cross Country Dataset

Growth of labour productivity in the countries chosen diverges to a certain extent over the period of time studied. While most countries experienced a clear down turn in connection with the economic crisis in the early 00s, and a negligible productivity increase thereafter followed by a further contraction in 2007-2008, Sweden stands out with its persistent productivity growth. France and the United Kingdom, with similarly lower levels of ICT (and general) human capital as well as ICT adoption compared to the other countries, differ markedly. The latter shows a more cyclical volatility meanwhile the former coincides with the steady but slow growth of the two other small open economies. These differences might relate to the level of flexibility and to the countries' capacity to adjust to shocks. Yet, the results are a bit contradictory, because the United Kingdom has the least rigid labour market legislation in the group and could thus have been expected to adjust its productivity far smoother than the other countries. The lack of such results may indicate that underlying problems from earlier crises have not yet been dealt with properly.

Estimation metrics

The estimations will be performed on the unbalanced pooled panels of firms including the years 2001 to 2009 for France, Finland Norway, Sweden and the United Kingdom[4]. With this some of the variables discussed theoretically also change to their estimation names.

Several alternative measures of productivity can be calculated, both single and multifactor ones. Pointing out what is most relevant for the impacts regression including real human capital is not uncomplicated and the literature gives no clear recommendation on what measure to highlight, but rather on how to calculate different productivities. However, the focus here will be steered towards labour productivity since it is the most used measure of productive efficiency; is less difficult to calculate and is easier to compare across countries.

Labour productivity (LPV) will be based on the value added, which itself originates from the gross production value exclusive of the services and intermediate inputs.

[4] Human capital data for Finland is only available up to the year 2008.

Bartelsman and Doms (2000) favour the gross values on the basis that the shift in the use of intermediate inputs relative to capital and labour over time may otherwise create bias in the productivity measure. This is also emphasised by Bailey (1986) and Basu and Fernald (1995). However, in this paper we use the value added based productivity metrics. The decision to do so is rather practical than theoretical and follows from the fact that intermediate inputs are dealt with differently among countries.

Table 4. Estimation variables

Variable	Estimation variable	Description
y	LPV	Value added
l	E	Number of employees
s^l	HKpct	Proportion of employees with post upper secondary education
	HKITpct	Proportion of employees with post upper secondary ICT intensive education
	HKNITpct	Proportion of employees with post upper secondary general education
z	AGE	Firm age
	AGE2	Firm age squared
x	BROADpct	Firm proportion of broadband Internet enabled employees
	MOB	Firm has mobile connection
(s^l)*(x)	HKBROAD	Proportion of employees with post upper secondary education interacted with firm proportion of broadband Internet enabled employees
d^c	MNC	Multinational firm=1
	EXP	Exporter=1
	Size class	Eight size classes*
d^f	Industry	EUKLEMS 2-digit industry
	Time	Year

*The firms have been grouped in eight size classes:
0 if Emp=0
1 if 0>Emp<10
2 if 10≥Emp<20
3 if 20≥Emp<50
4 if 50≥Emp<100
5 if 100≥Emp<250
6 if 250≥Emp<500
7 if Emp≥500

Since the computation varies somewhat across countries, the capital variable will not be included in the regressions. The returns to scale are instead assumed to be captured by the detailed size class dummies. All current prices or values are deflated by country specific EUKLEMS/National Accounts industry deflators, producer prices or investments indices. In aggregated analyses, like growth accounting, hours worked is the measure often favoured for the labour input to productivity calculations, but such data are only available for a sample of individuals and thus cannot be used in this context.

With the two human capital variables (HKITpct) and (HKNITpct), reflecting the ICT intensive and generally skilled human capital respectively, the effects on productivity can be observed as well as whether the addition of new variables and changes of the datasets affect single estimates. As opposed to what is described theoretically, the human capital variables will not be estimated in their logarithms. They are already linear as proportions of firm employees. Firm generation (AGE) and age squared (AGE^2), controlling for non-linearity may also be of importance for productivity.

The proportion of broadband Internet enabled employees (BROADpct) and whether the firm has mobile connections to Internet (MOB) are the two variables meant to capture different phases of firm ICT maturity. Both ICT variables could as well in certain contexts be considered proxies for process innovations, that is, new ways of handling firm operations as hinted at by Farooqui and Van Leeuwen (2008) for instance. Included are also the dummy variables holding differences among industries and changes over time constant as well as dummies controlling for firm characteristics such as size, international experience and affiliation. The firm is considered internationally experienced if it undertakes exporting activities and the affiliation dummy tells whether the firm is multinationally connected. Firms with zero or missing productivity values are excluded.

Discussion of results

The stepwise regressions show stability over the different specifications in the effects on productivity from ICT human capital in all countries except the United Kingdom. ICT intensive as well as generally skilled human capital boost productivity although the magnitudes differ both among countries and industries. Finland and Norway receive the largest productivity bonuses from increases in the firm proportion of ICT skilled human capital, while France and Sweden are lagging behind and with the United Kingdom somewhere in between.

Table 5A. Direct effects on firm productivity from ICT intensive human capital

OLS estimations on unbalanced panel of firms
Per cent

PSEC 2001-09	FI 1	3	5	FR 1	3	5	NO 1	3	5
LnE	0.862	0.857	0.856	0.907	0.899	0.894	0.980	0.975	0.975
	0.011	*0.011*	*0.011*	*0.005*	*0.005*	*0.005*	*0.012*	*0.012*	*0.012*
HKITpct	0.915	0.870	0.867	0.638	0.563	0.548	0.958	0.890	0.891
	0.026	*0.027*	*0.027*	*0.034*	*0.034*	*0.034*	*0.048*	*0.049*	*0.049*
HKNITpct	0.784	0.724	0.719	1.301	1.184	1.160	0.738	0.661	0.661
	0.023	*0.026*	*0.026*	*0.022*	*0.022*	*0.022*	*0.033*	*0.035*	*0.035*
AGE		0.000	0.000		0.006	0.006		0.009	0.009
		0.001	*0.001*		*0.000*	*0.000*		*0.001*	*0.001*
AGE2		0.000	0.000		0.000	0.000		0.000	0.000
		0.000	*0.000*		*0.000*	*0.000*		*0.000*	*0.000*
BROADpct		0.068	0.064		0.212	0.198		0.120	0.119
		0.013	*0.013*		*0.008*	*0.008*		*0.015*	*0.015*
MOB			0.023			0.085			0.021
			0.009			*0.007*			*0.024*
EDF	20682	20325	20324	46441	46130	46129	15031	14685	14684
RSQ	0.89	0.89	0.89	0.90	0.90	0.90	0.89	0.89	0.89

Note: Finnish estimations refer to the years 2001-08 and French to the years 2001 and 2006-09. Included but not reported here are dummy variables holding time and industry fixed as well as dummies for size class, international experience and affiliation. Robust standard errors are shown in *italic* and all results are significant at the one per cent level except those in dark shade that are not significant at all or those in fair shade that are significant at a lower level.

Source: ESSnet on Linking of Microdata on ICT Usage Project Cross Country Dataset

A one per cent change in the share of ICT intensive human capital increases firm productivity almost proportionally both in Finland and Norway. However, two completely different patterns are discovered. In France and Sweden, the effects on productivity are stronger from generally skilled human capital; meanwhile the reverse is true for Finland, Norway and the United Kingdom. Some of these results go in the opposite direction of those presented by Ilmakunnas and Maliranta (2005), who found that non-technological education gave the strongest boost to productivity. Our findings indicate that different channels may be responsible for the transmission of ICT-related assets into productivity gains. Such channels can be associated, for instance, with the structure of the economy (services versus manufacturing) or with the country-specific relations between different kinds of human capital and IT maturity.

Table 5B. Direct effects on firm productivity from ICT intensive human capital

OLS estimations on unbalanced panel of firms
Per cent

PSEC 2001-09	SE 1	3	5	UK 1	3	5
LnE	0.952	0.949	0.947	0.977	0.985	0.976
	0.009	*0.009*	*0.009*	*0.011*	*0.011*	*0.011*
HKITpct	0.652	0.563	0.561	0.806	0.426	0.413
	0.0338	*0.034*	*0.034*	*0.066*	*0.064*	*0.064*
HKNITpct	0.706	0.601	0.597	0.379	0.183	0.180
	0.033	*0.034*	*0.034*	*0.042*	*0.040*	*0.040*
AGE		0.024	0.025		0.008	0.008
		0.002	*0.002*		*0.003*	*0.003*
AGE2		-0.001	-0.001		0.000	0.000
		0.000	*0.000*		*0.000*	*0.000*
BROADpct		0.173	0.168		0.830	0.802
		0.011	*0.011*		*0.023*	*0.024*
MOB			0.026			0.130
			0.008			*0.017*
EDF	25584	24698	24697	13898	13895	13894
RSQ	0.92	0.92	0.92	0.65	0.68	0.68

Note: Included but not reported here are dummy variables holding time and industry fixed as well as dummies for size class, international experience and affiliation. Robust standard errors are shown in *italic* and all results are significant at the one per cent level except those in dark shade that are not significant at all or those in fair shade that are significant at a lower level.
Source: ESSnet on Linking of Microdata on ICT Usage Project Cross Country Dataset

When the ICT maturity variables are added to the regressions, starting with BROADpct, the human capital effects decrease slightly in most countries except in the UK where the size of the estimates are almost reduced by halves. Although significant and positive, the influence on productivity by Broadband Internet enabled employees is generally smaller than from the human capital. This is particularly noticeable for Finland and Norway, and also contrasts the picture of the United Kingdom. When finally a dummy variable for the firm mobile connection is included, not much noise is stirred up across the samples. This link is tiny in most countries. Moreover, firm productivity in Norway does not seem to be related at all to the availability of mobile connections. UK stands out in these results and shows the highest importance of both ICT maturity variables for productivity compared to the other countries: the productivity effect of ICT human capital seems to be clearly separable from the productivity effect of IT maturity here. Nevertheless, it is important to note that the R-squared is visibly lower for the United Kingdom, implying that the fit of the model is not as good as for the rest of the countries studied. On the general level these results are in line with those found by Blake and Lynch (1996) Rao et al (2002) and Niringiye (2010), that is, increases in the proportion of skilled human capital boost productivity. However, like Iranzo et al (2008) point out, kind of human capital seems to be of certain weight.

The high adoption level of ICT in Finland coincides with their rather small gains from ICT maturity as compared with the ICT intensive human capital. A high ICT maturity could indicate that the gains have already been taken. The Norwegian pattern shows similar tendencies meanwhile Sweden, who is also a heavy user, still gains from increases in ICT maturity as well as from ICT intensive human capital, but the latter on a more modest level. This link to ICT maturity also mirrors earlier work by Hagsten and Kotnik (2008) and Bartel et al (2007), for instance.

If instead the manufacturing and services firms are studied separately, an alternative pattern appears, as is shown in Table 6. The strongest boost on productivity comes from the services firms, whose labour productivity seems to be slightly less dependent on kind of skilled human capital. On the other hand, the spread between the two groups of human capital is wider for the manufacturers and particularly so for France and Norway, but in different directions. Meanwhile Norway has the largest productivity premium from ICT intensive human capital; France shows by far the strongest effects from generally skilled human capital among its manufacturers.

The results appear to indicate that the channels through which human capital can target productivity, as described for instance by Durbin (2004) are indeed established. Yet, there is a suggestion that the ICT intensive human capital is of particular importance for making better use of the real capital inputs while the generally skilled human capital mainly contributes to productivity by its flexibility and ability to generate spillover effects. Additionally, ICT may generate productivity effects that are larger than would be predicted by considering the quantity of the related input (human capital in our case). These effects are usually associated with the nature of ICT as a general purpose technology and in our sample are most clearly observed for Norway (especially for the manufacturing sector). While this country falls behind Finland and Sweden in proportion of ICT human capital (see Descriptive data), it seized the highest productivity gains from ICT intensive labour.

Table 6. Direct effects on firm productivity from ICT intensive human capital by industry

OLS estimations on unbalanced panel of firms
Per cent

PSEC 2001-09	Manufacturing					Services				
	FI	FR	NO	SE	UK	FI	FR	NO	SE	UK
LnE	0.974	0.938	0.933	0.988	1.102	0.787	0.877	1.002	0.953	0.962
	0.017	*0.009*	*0.024*	*0.014*	*0.022*	*0.016*	*0.007*	*0.016*	*0.014*	*0.013*
HKITpct	0.713	0.442	1.160	0.360	0.271	0.894	0.564	0.829	0.533	0.485
	0.058	*0.154*	*0.122*	*0.086*	*0.096*	*0.034*	*0.039*	*0.056*	*0.039*	*0.090*
HKNITpct	0.509	1.558	0.264	0.550	0.133	0.795	1.024	0.726	0.701	0.198
	0.057	*0.048*	*0.086*	*0.085*	*0.092*	*0.031*	*0.029*	*0.041*	*0.040*	*0.048*
AGE	0.000	0.004	0.006	0.019	0.006	0.002	0.009	0.012	0.030	0.020
	0.001	*0.001*	*0.002*	*0.004*	*0.005*	*0.001*	*0.001*	*0.002*	*0.003*	*0.005*
AGE2	0.000	0.000	0.000	-0.001	0.000	0.000	0.000	0.000	-0.001	-0.001
	0.000	*0.000*	*0.000*	*0.000*	*0.000*	*0.000*	*0.000*	*0.000*	*0.000*	*0.000*
BROADpct	0.044	0.200	0.207	0.152	0.704	0.063	0.215	0.086	0.172	0.807
	0.024	*0.015*	*0.029*	*0.021*	*0.044*	*0.016*	*0.012*	*0.019*	*0.014*	*0.029*
MOB	0.005	0.069	0.032	0.038	0.051	0.039	0.096	0.021	0.021	0.188
	0.013	*0.011*	*0.041*	*0.013*	*0.025*	*0.012*	*0.010*	*0.032*	*0.011*	*0.022*
EDF	7744	15852	4655	7869	4381	10182	22204	8652	13499	8697
RSQ	0.90	0.92	0.89	0.93	0.73	0.88	0.88	0.89	0.91	0.66

Note: Finnish estimations refer to the years 2001-08 and French to the years 2001 and 2006-09. Included but not reported here are dummy variables holding time and industry fixed as well as dummies for size class, international experience and affiliation. Robust standard errors are shown in *italic* and all results are significant at the one per cent level except those in dark shade that are not significant at all or those in fair shade that are significant at a lower level.
Source: ESSnet on Linking of Microdata on ICT Usage Project Cross Country Dataset

The ICT maturity in the shape of broadband Internet enabled employees does not deviate largely from what was found for firms on average, with the exclusion of Norway, where the results reveal that the productivity bonuses mainly come from the manufacturers. Although the uptake of mobile connections did not vary much over type of industry, the impact is higher and more often significant for the services firms. Norwegian firm performance is still not affected at all by mobile connections, nor is its Finnish equal. Sweden, on the other hand, with the next highest level of adoption is way behind the impact on the United Kingdom services firms.

Mason and Firth (2004) concludes that a deficit of specialized skills would not only restrict adoption, but also limit possible benefits from ICT. This does not exactly seem to be the route among the countries investigated here. The United Kingdom, with a low proportion of generally skilled human capital gains hugely from ICT maturity, while Finland, with both ICT- and generally skilled human capital proportions high, receives only marginal effects from increases in the ICT maturity. This could reveal that the effects from ICT maturity are more easily depleted. In the United Kingdom, where the human capital boost was clearly reduced when ICT maturity was introduced, the simple explanation could be that ICT human capital and maturity to a certain extent are substitutes, or that the ICT maturity is in fact a proxy for skills achieved outside the formal educational system. This feature is not very obvious in any other country.

Table 7. Intensities and impacts of ICT human capital and maturity

High proportion		High impact	
HKIT	BROADpct	HKIT	BROADpct
FI	FI	NO	**UK**
UK	SE	FI	**FR**
SE	NO	SE	SE
NO	**UK**	FR	NO
FR	**FR**	UK	FI

Source: ESSnet on Linking of Microdata on ICT Usage Project Cross Country Dataset

In Table 7, the countries are ranked by their level of ICT human capital, ICT maturity as well as the magnitude of the effect on productivity from these same variables. The ranking supports the findings that no such simple reverse effect that seems to exist for the ICT maturity (high adoption – productivity effects already depleted) could be found. Nor could any systematic cross effects be traced.

As hinted at by Acemoglu (1998) and found by Gunnarsson et al (2004), ICT and human capital could well be expected to complement each other. We test this hypothesis by introducing an interaction term between the proportion of employees with post upper secondary education and the proportion of broadband internet enabled employees. The estimates are presented in Table 8. Though this premise does not fit the United Kingdom very well, the results for the other countries do not contradict that such channels would be open.

Table 8. Indirect effects on firm productivity

OLS estimations on unbalanced panel of firms
Per cent

PSEC	Manufacturing					Services				
2001-2009	FI	FR	NO	SE	UK	FI	FR	NO	SE	UK
lnE	0.974	0.940	0.936	0.989	1.104	0.789	0.880	1.000	0.955	0.975
	0.017	*0.009*	*0.024*	*0.014*	*0.022*	0.016	*0.007*	*0.016*	*0.014*	*0.013*
HKpct	0.708	1.658	0.596	0.887	0.293	0.753	1.102	0.522	0.534	0.214
	0.076	*0.058*	*0.160*	*0.135*	*0.098*	0.051	*0.039*	*0.101*	*0.073*	*0.067*
AGE	-0.001	0.004	0.006	0.019	0.006	0.002	0.009	0.012	0.030	0.020
	0.001	*0.001*	*0.002*	*0.004*	*0.005*	0.001	*0.001*	*0.002*	*0.003*	*0.005*
AGE2	0.000	0.000	0.000	-0.001	0.000	0.000	0.000	0.000	-0.001	-0.001
	0.000	*0.000*	*0.000*	*0.000*	*0.000*	0.000	*0.000*	*0.000*	*0.000*	*0.000*
BROADpct	0.085	0.281	0.219	0.203	0.744	0.033	0.292	0.051	0.169	0.837
	0.036	*0.019*	*0.035*	*0.024*	*0.051*	0.023	*0.015*	*0.023*	*0.015*	*0.033*
HKBROAD	-0.155	-0.486	-0.028	-0.558	-0.174	0.121	-0.331	0.268	0.098	0.104
	0.102	*0.083*	*0.184*	*0.159*	*0.156*	0.060	*0.048*	*0.107*	*0.079*	*0.095*
EDF	7745	15853	4656	7870	4382	10183	22205	8653	13500	8698
RSQ	0.90	0.92	0.89	0.93	0.73	0.88	0.88	0.89	0.91	0.66

Note: Finnish estimations refer to the years 2001-08 and French to the years 2001 and 2006-09. Included but not reported here are dummy variables holding time and industry fixed as well as dummies for size class, international experience and affiliation. Robust standard errors are shown in *italic* and all results are significant at the one per cent level except those in dark shade that are not significant at all or those in fair shade that are significant at a lower level.

Source: ESSnet on Linking of Microdata on ICT Usage Project Cross Country Dataset

By looking at the firm-level data for 2001-2005, Hagsten and Kotnik (2008) showed that Swedish services firms in particular gained from this complementarity. However the boost seems to have disappeared for this country when a longer period of time, with more recent years has been investigated. Instead there are now signs of an indirect effect on the manufacturers, although this time it reduces productivity. A similar impact is found for France; meanwhile there is no relationship for the rest of the manufacturers. French services firms are negatively affected as well, while both Norwegian and Finnish ones do in fact gain from an indirect effect. Swedish firms do not, as is the case with the United Kingdom.

Though these results seem to be somewhat contradictory, they might point at different phases of development in the countries studied. A non-significant estimate could either indicate that there is still some catching up to do before gains could be reaped, or it could as well mean that the bonus stages have already been passed. Moreover, although the ICT maturity still effects most firms to a certain degree, this is not really cutting edge technology (any more) and it does not take a university degree to use it, meaning that the full preconditions for an indirect effect are not necessarily there.

Concluding remarks

There are still computers everywhere, and the productivity gains from them have been clearly visible too, although these days such effects would rather arise from how you connect or use your computer than from just being in possession of it. However, part of the Solow riddle still remains to be solved; and in this paper we have attempted to meet the challenge of casting some more light on how the ICT intensive human capital fits into the picture, both on its own and together with the firm ICT maturity.

The estimations tell us that both ICT intensive human capital and ICT maturity are related to firm productivity in Finland, France, Norway, Sweden and the United Kingdom, mainly in a positive sense. However, the magnitudes of the effects and the channels through which the human capital operates seem to vary both among type of skills and industries as well as to a certain degree among countries. Generally, the impact on productivity is driven by the services firms, but this does not mean that the effect on the manufacturers is negligible. Finland and Norway are the ones that receive the highest productivity bonuses from ICT intensive human capital meanwhile France and Sweden gain more from generally skilled human capital. The United Kingdom is by far the country mostly affected by changes in the level of firm ICT maturity.

The channel for the ICT intensive human capital seems to be more narrow than for generally skilled human capital and might require a direct match with physical capital to release a full blown effect. Kind of human capital is of higher importance for the manufacturers. The services firms are more indifferent about orientation of education and the productivity effects from generally skilled human capital may sooner originate from a high level of flexibility and an ability to generate spillover effects, rather than from the narrowly specialized education.

The literature emphasises the complementarity between skills and ICT. Although the direct effects on productivity did not contradict the existence of such indirect impacts, the results show a certain disharmony. In the United Kingdom, the human capital and ICT maturity rather seem to substitute than complement each other. Norwegian and Finnish services firms were the only ones to gain from indirect effects. This can possibly tell something about the countries not being at similar ICT stages, although it is not uncomplicated to figure out who is in the lead. Another underlying reason could be that the ICT maturity itself no longer is advanced enough to match the highly skilled human capital into an indirect effect on productivity.

References

Acemoglu, Daron (1998) “Why do New Technologies Complement Skills? Directed Technical Change and Wage Inequality”, *The Quarterly Journal of Economics*, November, pages 1055-1089

Bailey, Martin Neil (1986) “Productivity Growth and Materials Use in US Manufacturing”, *The Quarterly Journal of Economics,* February, pages 185-195

Bartel, Ann, Casey Ichniowski and Kathryn Shaw (2007) “How Does Information Technology Affect Productivity? Plant level Comparisons of Product Innovation, Process Improvement and Worker Skills”, *The Quarterly Journal of Economics*, November, pages 1721-1758

Bartelsman, Eric J. and Mark Doms (2000) “Understanding Productivity: Lessons from Longitudinal Microdata”, *Journal of Economic Literature*, American Economics Association, volume 38(3), September, pages 569-594e

Bartelsman, Eric J. and Matthew Barnes (2001) “Comparative Analysis of Firm Level Data: A Low Marginal cost Approach”, Research report for the OECD

Bartelsman, Eric J. (2004) “The Analysis of Microdata from an International Perspective”, *STD/CSTAT (2004)12*, OECD

Bartelsman, Eric J. (2008) “ICT Impacts: From Micro to Macro”, *Final Report, Information Society: ICT impacts Assessment by Linking Data from Different Sources,* Chapter 14, Eurostat

Bartelsman, Eric J. and Zoltan Wolf (2009) "Forecasting Productivity Using Information from Firm-Level Data", *Tinbergen Institute Discussion Paper, volume 43, number 3*

Basu, Susanna and John G. Fernald (1995) "Aggregate Productivity and the Productivity of Aggregates”, *International Finance Discussion Papers 532,* Board of Governors of the Federal Reserve System (U.S.)

Basu, Susanna and John G. Fernald (2006) “Information and Communications Technology as a General-Purpose Technology: Evidence from U.S Industry Data”, *Federal Reserve Bank of San Francisco Working Paper Series* number. 2006-29

Black, Sandra E. and Lisa M. Lynch (1996) “Human Capital-Investments and Productivity”, *American Economic Journal*, Volume 86, number 2, May, pages 263-267

Bloom, Nicholas, Mirko Draca, Tobias Kretschmer and Raffaella Sadun (2010) “The Economic Impact of ICT”, SMART 2007/0020, *Final Report from the EU Commission project “Economic Impact of ICT”*, Centre for Economic Performance, London School of Economics, January

Bloom, Nicholas, Raffaella Sadun and John Van Reenen (2005). "It Ain’t What You Do it’s the Way You Do IT: Testing Explanations of Productivity Growth Using US Affiliates". *Mimeo, Centre for Economic Performance*, London School of Economics.

Bresnahan, Timothy F. and Manuel Trajtenberg (1995) “General Purpose Technologies: Engines of Growth?” *Journal of Econometrics,* number 65, pages 83-108.

Brynjolfsson Erik and Lorin M. Hitt (2000) "Beyond Computation: Information Technology, Organizational Transformation and Business Performance", *Journal of Economic Perspectives*, Volume 14, number 4, Fall, pages 23-48

Brynjolfsson Erik and Lorin M. Hitt (1995) "Information Technology as a Factor of Production", *Economics of Innovation and New Technology (Special Issue on Information Technology and Productivity Paradox),* number 3, pages 183-200

Brynjolfsson Erik and Lorin M. Hitt (2003) "Computing productivity: Firm-Level Evidence", *The Review of Economics and Statistics*, Volume 85, number 4, November, pages 793-808

Brynjolfsson Eric, Lorin M. Hitt, and Shinkyi Yang (2002) "Intangible Assets: Computers and Organizational Capital", *Brookings Papers on Economic Activity*, number 1, pages 137-198

Carlaw, Kenneth I. and Richard G. Lipsey (2006) “GPT-Driven Endogenous Growth.”, *Economic Journal*, number 116, January, pages 155-174.

Caroli, E. and John Van Reenen (2001). "Skill-Biased Organizational Change? Evidence from a Panel of British and French Establishments". *Quarterly Journal of Economics*, 116: 1449-92

Christensen Laurits R., Jorgenson Dale W. and Lawerence J. Lau (1973) "Transcendental Logarithmic Production Frontiers". *The Review of Economics and Statistics,* Volume. 55, Number 1, February, pages 28-45

Crespi, Gustavo, Chiara Criscuolo and Jonathan Haskel (2007) “Information Technology, Organisational Change and Productivity Growth: Evidence from UK firms”, *Centre for Economic Performance Discussion Paper*, number 783, May

Criscuolo, Chiara, Eva Hagsten, Aoife Hanley, Patrik Karpaty and Stefan Svanberg (2008) “Offshoring and Productivity: The Case of Ireland, Sweden and the United Kingdom, in *Staying Competitive in the Global Economy,* OECD

Doms, Mark, Timothy Dunne and Kenneth R. Troske (1997) “Workers, Wages and Technology”, *The Quarterly Journal of Economics*, February, pages 253-290

Draca, Mirko, Raffaella Sadun and John Van Reenen (2006) “Productivity and ICT: A Review of the Evidence”, *CEP Discussion Paper 0749,* Centre of Economic Performance, London School of Economics

Durbin, Sid (2004) “Workplace Skills, Technology Adoption and Firm Productivity: A Review”, *New Zealand Treasury Working Paper 04/6,* September

Farooqui, Shikeb and George Van Leeuwen (2008) “ICT, Innovation and Productivity” *Final Report, Information Society: ICT impacts Assessment by Linking Data from Different Sources*, Chapter 12, Eurostat

Forth John and Geoff Mason (2004) "Information and Communication Technology (ICT) Adoption and Utilisation, Skill Constraints and Firm-Level Performance:

Evidence from UK. Benchmarking Surveys", *National Institute of Economic and Social Research Discussion Paper No. 234*, March

Galindo-Rueda, Fernando and Jonathan Haskel (2005) "Skills, Workforce Characteristics and Firm-Level Productivity: Evidence from the Matched ABI/Employer Skills Survey", *Institute for the Study of Labour Discussion Paper Series*, IZA DP number 1542, March

Gunnarsson, Gudmundur, Erik Mellander and Eleni Savvidou (2001) "Is Human Capital the Key to the IT Productivity Paradox?*", The Research Institute of Industrial Economics Working Paper number 551*

Gunnarsson, Gudmundur, Erik Mellander and Eleni Savvidou (2004) "Human Capital is the Key to the IT Productivity Paradox", *Institute for Labour Market Policy Evaluation Working Paper 2004:13*

Hagsten, Eva and Patricia Kotnik (2008) "Employment, Skills and Information Technology", *Final Report, Information Society: ICT impacts Assessment by Linking Data from Different Sources*, Chapter 8, Eurostat

Ilmakunnas, Pekka and Mika Maliranta (2005) "Technology, Labour Characteristics and Wage-Productivity Gaps", *Oxford Bulletin of Economics and Statistics*, 67, 5(2005), pages 623-644

Iranzo, Susana, Fabiano Schivardi and Elisa Tosetti (2008) "Skill Dispersion and Firm Productivity: An Analysis with Employer-Employee Matched Data", *Journal of Labour Economics*, volume 26, issue 2, pages 247-285

Lichtenberg, Frank (1993) "The Output Contributions of Computer Equipment and Personnel: A Firm-Level Analysis", *NBER Working Paper Series,* WP number 4540, November

Niringiye, Aggrey, Eliab Luvanda and Joseph Shitundu (2010) "Human Capital and Labour Productivity in East African Manufacturing Firms", *Current Research Journal of Economic Theory* 2(2), pages 48-54

Rao, Someshwar, Jinamin Tang and Weimin Wang (2002) "The Importance of Skills for Innovation and Productivity", *International Productivity Monitor,* number 4, Spring, Centre for the Study of Living Standards, Canada

Solow, Robert M. (1956) "A contribution to the Theory of Economic Growth", *Quarterly Journal of Economics*, volume 70, number 1, pages 65-94

Solow, Robert M. (1987) "We'd Better Watch Out", *New York Times Book Review*, July 12th