# A Neglected Input to Production:
# The Role of Schooled ICT Experts in Firm Performance


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# A Neglected Input to Production: The Role of Schooled ICT Experts in Firm Performance

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***Abstract*** *(Please do not cite without permission from the authors.)*

Although there has been a considerable amount of theoretical and empirical discussions on the productivity effects of ICT physical capital and ICT general literacy of workers, the influence of highly specialised ICT human capital and ICT-enabled organisational adjustments has received insufficient attention. This paper broadens the perspective on how ICT relates to growth by studying the productivity effects of increases in the proportion of ICT-intensively educated employees in firms, an intangible input often neglected or difficult to measure. The effects are investigated both in isolation and in conjunction with the impact of ICT maturity in firms. Starting from an augmented Cobb Douglas specification and using the Ordinary Least Squares technique with aggregate and time-specific changes held fixed, we estimate the influences on firm productivity in six European countries using the unique *ESSnet on Linking of Microdata to Analyse ICT Impact* (ESSLait) panel dataset for the years 2001-2009. The results indicate that increases in the proportion of ICT-intensive human capital may indeed boost productivity, and that this effect is generally more persistent than that of ICT maturity gained from increases in the level of ICT usage. However, the gains vary across countries and industries, demonstrating that the channels through which the effects operate may be narrower for ICT-intensive human capital than for skilled human capital in general. The variations also indicate that other underlying factors such as industry structure and institutional settings may be of importance.

JEL codes: D22, D24, L810, I210

Key words: firm productivity, human capital, information technology

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[b]The views expressed in this paper are purely those of the authors and in no circumstances should they be regarded as stating an official position of the European Commission or Statistics Sweden. The results presented are based on the authors' own calculations on the datasets available within the ESSLimit Project and should not be confused with official statistics.

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## Introduction

Much has happened since the neoclassical economist Solow (1956) recognised technological change as an important influence on growth. He later expressed surprise in a New York Times book review that *you can see the computer age everywhere but in the productivity statistics,* Solow (1987). By this he meant that the technological revolution that many felt they had experienced was not accompanied by a growth in productivity, but rather by the reverse. This may of course have been for many reasons, and the economic literature has suggested two main explanations of the "Solow paradox". One of them is that there is a lag in the effect of information and communication technology (ICT), because the economy as a whole and its human capital need additional time and effort to adjust to new technologies. The other is that the available data may not be sufficiently detailed to allow detection of the effect.

The traditional macroeconomic measurement framework is not perfectly tuned to capturing the specificity of enabling technologies as an input to production, and typically underestimates or averages out 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 computerisation of the economy may be understated by a factor of 10. This bias is mainly due to the difficulty of adequately describing and measuring the mechanisms by which firm-level returns add up to industry- or economy-wide benefits, and to the difficulty of accounting for complementary enabling factors.

In the last decade, several studies have addressed the above shortcomings of the macroeconomic approach by going beyond a traditional growth accounting method, in particular by applying firm-level analysis (see Brynjolfsson and Hitt, 2000, for a detailed literature review). These studies suggest that productivity performance at the macro-level has its roots in many years of computer-enabled organisational adjustments made at the firm-level, and is strongly related to large investments in intangible assets. Studies that encompass the effects of different kinds of investment in ICT on aggregate and disaggregate economic performance are well-known: Draca et al (2006) summarise a wide range of research on the relationship between ICT and productivity, both from the growth accounting and the econometrics standpoints, and found that most studies report a positive and statistically significant impact of ICT on productivity.

Firm-level analysis has significant measurement advantages for examining intangible organisational investments that accompany ICT products and services innovations, and the ways they are used or connected. However, while analyses at the firm-level help control for many biases that result from aggregation, it is often difficult to find good quality data representative of national economies, let alone multinational regions. Brynjolfsson and Hitt (1995) and Lichtenberg (1993) have explored firm-level data for the United States, while the Eurostat ICT impact projects provide the most informative data to-date on European ICT-led productivity gains. The latter data have been explored by a number of investigators, including van Leeuwen (2008) and Bartelsman (2008), who found that ICT investments and ICT maturity (approximated by ICT usage) boost productivity. Based on theoretical reasoning and on empirical evidence, productivity gains can thus be regarded, in part, as deriving from organisational capital (Caroli and Van Reenen 2001, Brynjolfsson et al, 2002, Brynjolfsson and Hitt 2003, Bloom et al 2005) and as being conditional on unmeasured complementary factors, first and foremost human capital.

Although human capital has been the focus of productivity studies for many years, and the issues of how and to what extent higher education affects growth are frequently high on political agendas, the role played by *different kinds* of human capital has often been neglected by academia and by policy makers.

The adoption in May 2010 of the *Digital Agenda for Europe (DAE)*[1], the EU strategy, meant to take advantage of the potential offered by the rapid progress in information and communication technologies, renewed the strong European policy focus on the role ICT plays for growth. However, so far the theoretical and empirical discussion has largely revolved around the impact of ICT physical capital and ICT general literacy of workers on productivity, while the influence of highly specialised ICT human capital and ICT-enabled organisational adjustments has not received sufficient attention. The various policy initiatives of the Europe 2020 overall strategy (the *Agenda for New Skills and Jobs (2010)*[2], *Employment package*, *Resource-Efficient Europe*, and *Youth*) lack a comprehensive approach encompassing the complexity of the ICT-employment-productivity nexus, and often fail to specify mechanisms of interaction between ICT-specialised human capital and other assets.

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[1] DAE is a part of the overall Europe2020 strategy for smart, sustainable and inclusive growth, http://ec.europa.eu/digital-agenda/en/our-goals

[2] EC (2010b), http://ec.europa.eu/social/main.jsp?catId=958&langId=en

Yet, some studies (for instance by, Black and Lynch, 1996, Rao et al., 2002, Iranzo et al., 2008, and Niringiye et al., 2010) have pointed not only to the importance of skilled labour in increasing firm productivity but also suggest that type of human capital may be crucial, even if the effects of ICT skills are not investigated specifically. Bloom et al (2010) argued that the effect of ICT on productivity may depend on organisational readiness. Bartel et al (2007) found that ICT may affect all stages of production and may also change the demand for labour, which could be seen as an indication of the importance of specific skills for firm performance.

Ilmakunnas and Maliranta (2005) took a step towards accounting for kind of skill in a study showing that non-technical education had a stronger positive effect than technical education on firm productivity in Finland. Similarly, Hagsten and Kotnik (2008) have shown that under certain circumstances, ICT-intensive human capital affected firm performance differently from generally skilled human capital, and Gunnarsson et al (2001, 2004) found that the impact of skills upgrading on firm performance was stronger than the impact of firm performance on skills upgrading, when technology is held constant. They also found that ICT in the shape of investments was complementary to skills. This conclusion accords with Acemoglu's (1998) general view on technological change, and is particularly consonant with his suggestion that ICT is a complement rather than a substitute to skills. Forth and Mason (2004) drew a distinction between the skills necessary for ICT adoption versus those needed for utilisation, and investigated the impact of skill constraints on firm-level performance. They found that reported ICT skill deficiencies at firm level restricted the adoption of ICT, and limited the benefits gained from using ICT once the required investments had been made.

In short, recent research on the behaviour of firms has established that both ICT and human capital are important for firm performance, although these entities are more seldom analysed together but rather one at a time. Nor has the specificity of kind of skills received particular attention.

In this paper, we suggest a framework that captures several nuances associated with the impact of ICT as a general purpose technology on productivity, as discussed, for instance, by Basu and Fernald (2006). Our approach sheds light on an aspect of the productivity contribution of ICT that is often ignored in economic analysis, potentially leading to an underestimation of the returns brought by ICT. In our line of work we have the opportunity to, as part of a small group of pioneers, explore the unique datasets of the *ICT Impacts ESSNets (*ESSLimit and ESSLait), and report the results of several extensions to the aforementioned efforts to shed more light on Solow's paradox. In this paper we broaden the perspective on how ICT relates to growth by studying the productivity effects of increases in the proportion of ICT-intensively educated employees in firms, the intangible input often neglected or difficult to measure. The effects are investigated both in isolation and in conjunction with the impact of ICT maturity in firms.

Firstly, we measure intangible complementarities derived from the nature of human capital employed in production, by discriminating between generally skilled and ICT-intensive human capital. Secondly, we test for the productivity effect of ICT-enabled organisational adjustments undertaken at the firm-level, and mainly related to investments in intangible assets. We capture these organisational adjustments by the ICT maturity of a firm. Thirdly, we distinguish between the productivity effects of two groups of firms with different production processes, namely manufacturing and services. Finally, we analyse all of the above-mentioned effects on firm performance separately for six European countries – Denmark, Finland, France, Norway, Sweden and the United Kingdom. We provide indications of important country differences in the use of ICT and in its impact on firm output that can be partially attributed to the variety of country-specific channels by which ICT investments translate 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).

In the next section, we present the methodology underlying the analysis. This is followed by a section including descriptive data of the countries studied. Subsequently, the estimation metrics are described, and the results are discussed. Finally, we offer some concluding remarks.

## Method

In the analysis, we build on mainstream research that applies the economic theory of production to determine the contributions of various inputs to output. The production theory allows us to define the structure of the relationship between a set of relevant variables and the output in question. This relationship is estimated econometrically, and the estimates are compared with theoretical predictions. Thus, for any given set of inputs, a production function determines the maximum amount of output that can be produced, according to existing technology.

We start by assuming that firms produce a homogeneous product, and use the Cobb-Douglas specification as the first approximation of the arbitrary production function. In cases like ours, with more than two production inputs, a general functional form such as the transcendental logarithm (translog) would fit better than the more restrictive Cobb-Douglas specification (Christensen et al., 1973). However, Brynjolfsson and Hitt (1995, 1997) found no significant difference in the contribution of ICT to productivity when the constraint imposed by the Cobb-Douglas specification was relaxed.

As in other microdata studies (for instance, Ilmakunnas and Maliranta, 2005, Black and Lynch, 1996, and Brynjolfsson and Hitt, 1995, 1997, and 2003), firm output can be expressed as:

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

where ($A$) is a constant representing technology, ($K$) is capital and ($L$) is labour. Coefficients ($\alpha$) and ($\beta$) are the output elasticities of each input with a given technology. The partial output elasticity of the production function measures the percent change in production resulting from a unit increase in the input in question. If the coefficients add up to one, the production function exhibits a constant return to scale. However, the Cobb-Douglas specification can also accommodate increasing or decreasing returns to scale.[3]

The multiplicative form of the Cobb-Douglas can be transformed to obtain a specification that has linear parameters and is thus suitable for using the Ordinary Least squares (OLS) estimator. This transformation also facilitates separate analyses of the parameter estimates. Production can then be specified for each firm $i$ at time $t$ where $lnA$ is the productivity coefficient and $\varepsilon_{it}$ is the error term.

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

To operationalise this theoretical framework within the present context, we assume that a differentiation between types of human capital allows us to test for distinct

[3] The restriction implied by the Cobb-Douglas form is that the elasticity of substitution between factors is constrained to be equal to (-1). This means that the price increase of a particular input leads to a proportionate decrease in the amount of this input. The quantities of other inputs in production will increase to maintain the same level of output. As a result, the Cobb-Douglas formulation is not appropriate for determining whether inputs are substitutes or complements, and other, less restrictive, functional forms such as the transcendental logarithmic function need to be used. See Brynjolfsson and Hitt (1997) for testing several different production functions on microdata.

productivity gains. To carry out this test, we move beyond the historical division between skilled and unskilled labour to distinguish between *two types of skilled labour* – ICT-intensive and generally highly skilled human capital ($S^l$). To our knowledge, the only attempts to measure the special role played by ICT-trained staff were made by Brynjolfsson and Hitt (1997), who included "ICT labour" and "other labour and expenses" in their production function, and by Airaksinen et al (2012), who studied ICT skills, experts and outsourcing in the context of firm performance improvements.

However, the general level of ICT literacy is becoming increasingly important at practically all stages of production and distribution, is often acquired through learning-by-doing and, as a rule, is resistant to measurement. Since basic computer skills have become an essential part of the production behaviour of virtually all employees, they no longer estimate the comparative advantage of employing ICT-specialised personnel. Hence, by ICT-intensive human capital we do not mean to refer to the general level of ICT literacy, but rather to deep knowledge of ICT, officially certified by educational credentials. We believe that these specific skills are related to comparative advantages in operating information technologies and that they can stimulate and enable complementary innovations.

Thus, we can describe the channels through which human capital is expected to affect productivity as Durbin (2004) did: that is, through the efforts of highly skilled employees, who generate and benefit from knowledge spillovers and who make better use of inputs to production. This implies that the impact on productivity may be either direct or indirect, without it necessarily being the case that all kinds of firms gain from similar types of human capital, or that ICT-intensive human capital automatically translates instantaneously into productivity boosts.

Some additional considerations are required if we want to model ICT as a production input. If ICT is primarily an investment good, as claimed for example by 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 (1995), Carlaw and Lipsey (2006), Brynjolfsson and Hitt (2000), Brynjolfsson et al. (2002), it is an investment of a special kind, a general purpose technology. The productivity impact of general purpose technologies is known to be substantially larger than would be expected from considering the quantity of capital investment in combination with a normal rate of return. The output elasticity of ICT can thus be greater than its input share, indicating 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 the direct effect of ICT investment, and to break down 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 ICT but is materialised through different types of channels. Let us assume that the first type of technology effect captures productivity shocks at the aggregate (country and industry) level, while the second type can vary at firm level. These impacts are often jointly called multifactor productivity and in most studies there is no clear distinction between them.

*Aggregate productivity shocks* ( $D^f$ ) can be identified by two dummy variables: the first captures effects specific to the industry in which the firms operate and the other captures the time-specific variations in productivity. Thus, by holding industry and time effects fixed, we account for short-term productivity shocks within each industry and longer-term disembodied technological change at the country level.

Moreover, like Bartelsman and Wolf (2009), we assume that there is a *firm-specific productivity shock* ( $\delta$ ) unobservable to the econometrician but known to the firm (at least up to its expected value). By allowing for cross-firm variation in ( $\delta$ ), 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 organisational capital*. This organisational capital determines the ways in which ICT assets translate into productivity gains at the firm level. Thus, we assume that firms' decisions regarding investment in ICT capital (real or human) are conditional on unmeasured productivity-enhancing characteristics (such as, for example, management skills or expertise and experience in operating ICT technologies). Failure to account for these effects leads to an imprecise estimation of the productivity impact of other inputs.

There are several ways to get around this type of omitted variable bias. 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” effects, while elasticities of other inputs are not significantly affected. However, Ilmakunnas and Maliranta (2005) found that the use of the “within” estimator can wipe out too much of the data variation and therefore introduced a vintage variable (firm age) which captures the unobserved effects, at least to some extent.

Another approach is to introduce a firm-specific dummy variable and to estimate the productivity equation using the OLS technique, assuming maximum likelihood estimates under the normality assumption for the error term. However, this involves certain difficulties. The first is related to the large sample of firms in our panel and to the data construction specificities (see more details on this in the next section), which make application of the fixed-effect technique unfeasible. The second is due to firm-specific organisation capital being an incidental parameter, that is, a parameter that depends on a finite number of observations. The incidental parameters problem implies that, in short panels, joint estimation of fixed effects and other parameters generally leads to inconsistent estimation of all parameters.[4]

Among the econometric methods that suggest solutions to the incidental parameters problem[5], the most suitable in our case would seem to be the method of parameterisation introduced by Cox and Reid (1987) and further developed by Lancaster (2002). This approach makes it possible to secure estimators of common parameters that are not only consistent but also exact for any size and length of panel. Following this approach, we parameterise firm-specific time-invariant parameters, each of which determines the ways ICT is translated into productivity gains, and depends on a finite number of observations.[6] We control for a fixed productivity effect by introducing a set of variables that jointly characterise firm-specific organisational capital. One group of variables is related to vintage ($Z$), which we include because firm age itself may be of importance for productivity. Moreover, we include age squared since this should reveal any non-linear relationship. Additionally, we introduce dummy variables controlling for firm characteristics, ($D^c$). A number of studies (for instance,

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[4] The incidental parameters problem is known to econometricians since 1948 when Neyman and Scott wrote their seminal paper, and has since been documented in a vast number of studies such as Nerlove (1968), Nickell (1981) and Lancaster (2002).
[5] See, for example, Li and Leon-Gonzalez (2009) for a review.
[6] Lancaster (2002) offers a full econometric derivation of this procedure for, a number of models, including linear models with exogenous covariates and additive fixed effects. Econometrically, the main idea is that incidental parameters and common parameters are information-orthogonal.

Criscuolo et al., 2008) have found that larger firms tend to operate on higher productivity levels. It has also been demonstrated that being internationally active or affiliated positively affects productivity. Based on this evidence, we control for firm characteristics such as size, international experience and affiliation.

Additionally, we assume that those forms of intangible organisational capital that are related to firms' decisions to engage ICT in production will be captured by the ICT maturity variable ($X$). Higher ICT maturity in the shape of firm usage should translate into more effective investment decisions with regards to ICT capital and labour. Firms that are more intensive in using ICT are expected to benefit from their expertise, equipment and business relations, and to be more capable of acquiring and exploiting productivity-enhancing ICT.

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

$$lnY_{it} = \beta_0 + \beta_1 \ln K_{it} + \beta_2 \ln L_{it} + \beta_3 ln\boldsymbol{S}_{it}^{l} + \beta_4 X_{it} + \beta_5 \boldsymbol{Z_{it}} + \beta_6 \boldsymbol{D}^{c} + \beta_7 \boldsymbol{D}^{f} + \varepsilon_{it} \quad (3)$$

where $\varepsilon_{it}$ is a stochastic term representing white noise.[7]

In order to investigate whether human capital affects productivity more strongly on its own or (as suggested by Acemoglu, 1998) as a complement to ICT, an interaction term can be created. Like Gunnarsson et al (2004), we introduce an interaction, but instead of ICT investments we allow both the ICT-intensive capital and generally skilled human capital to vary with ICT maturity ($S^l X$). 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 us to estimate the coefficients specific to these sectors.

### Description of the dataset

*Construction*

The unique data used in this analysis originate from the national and cross-country sets constructed within three projects: *Eurostat ICT Impacts, ESSnet on Linking of Microdata on ICT Usage and ESSnet on Linking of Microdata to Analyse ICT Impact.*[8]

[7] Since $s^l$ and $u^l$ comprise hundred per cent of the employees, only one of them needs to be included in the estimations.

[8] Eurostat Grant agreements 49102.2005.017-2006.128, 50701.2010.001-2010.578 and 50721.2013.001-2013.082.

[8] See Awano (2012).

These datasets consist mainly of information collected from business registers, production surveys, EU-harmonised firm ICT usage surveys, community innovation surveys and to a lesser extent other registers.

Because access to data on individuals and firms is restricted in most countries, we needed a way to work around this obstacle. The tool we used is called the *Common Code,* based on the *Distributed Microdata Approach (DMD),* as described by Bartelsman and Barnes (2001), Bartelsman (2004) and Eurostat (2008), among others. This approach allows code modules to be run directly on the harmonised 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 practice relies heavily on careful initial analyses of metadata in order to ensure the comparability of the data used[9].

While the DMD approach has the substantial advantage of affording access to otherwise strictly protected data, it also has some drawbacks. In the present case the estimation methods need to be adoptable on all countries, and the methods used cannot be more advanced than co-ordination from a distance allows. This means that the virtue of comparability across countries should be emphasised and that the regression estimates should be considered as indications of causality and magnitude rather than as pure evidence.

**Table 1. Number of firms and sample overlaps**

| 2009 | DK | FI | FR | NO | SE | UK |
|---|---|---|---|---|---|---|
| **Production survey (PS)** | 200298 | 133721 | 39841 | 271701 | 814067 | 45169 |
| **ICT usage survey (EC)** | 4128 | 2939 | 9389 | 4041 | 3347 | 5456 |
| **Linked PSEC** | 3939 | 2925 | 9389 | 3897 | 3347 | 2533 |

Source: ESSLait dataset

Although the DMD approach allows wide combinations of information, in this study the production (PS) and ICT usage (EC) surveys are the ones most used. The production surveys are large in all countries: even though they are not always register-based as they are in the Nordic region, they nonetheless aim to be representative. However, for several reasons (for instance, easing the response burden for firms) samples may lack mutual coordination (small or non-existing overlaps). Unfortunately this may produce a selection bias, although that does not necessarily pose a major problem for the estimations. When Fazio et al (2006) investigated a dataset similar to the one used here

(United Kingdom), they found that marginal analyses are not particularly sensitive to a certain degree of selection bias. Further, they also showed that the use of industry and time dummies were crucial for robust regression estimates.

In the group of countries studied here, the linking of the datasets only leads to marginal losses of observations in the ICT usage survey, except in the case of the United Kingdom. The smaller overlap in the United Kingdom dataset may signify a more apparent bias towards larger firms than in the other five countries and follows from the fact that both the ICT and production surveys are sample-based.

Because data on educational achievements are not always available at firm level, only six countries out of fifteen were able to provide the information required to measure educational orientation of human capital. In Denmark, Finland, Norway and Sweden this is based on register data; in the United Kingdom the Community Innovation Survey is used and in France the information is derived from its occupation register.

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.

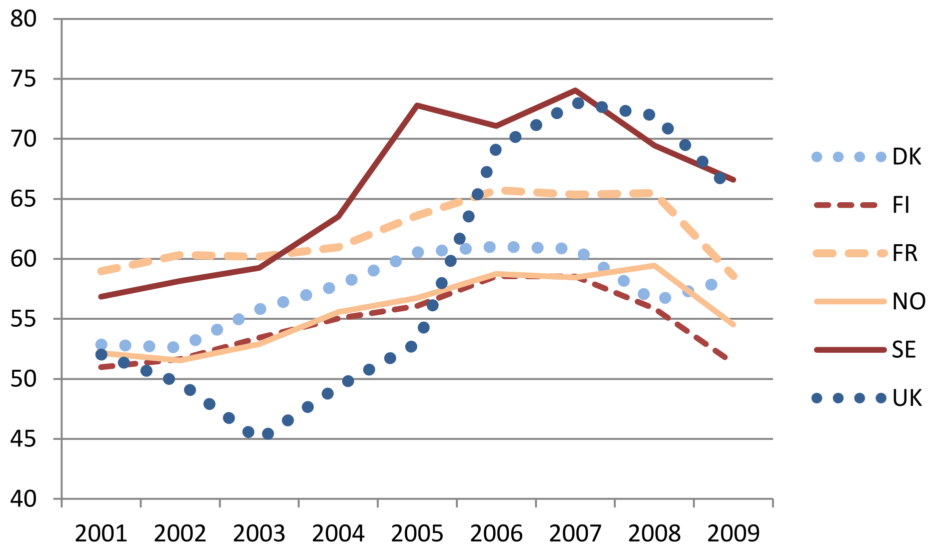
*Definition and description of variables*

The measure of productivity in our analysis is meant to reflect total factor productivity (TFP) and is based on value added (V), which itself originates from the gross production value exclusive of intermediate inputs. While Bailey (1986), Basu and Fernald (1995) and Bartelsman and Doms (2000) favour gross production values on the grounds that the shift in the use of intermediate inputs relative to capital and labour over time may otherwise create bias in the productivity measure, the ESSLait metadata analysis shows that value added is the most consistent measure across countries. The decision to use the value added-based productivity metrics follows from the fact that countries deal with intermediate inputs differently, which may confound the cross-country comparison. In aggregated analyses, like growth accounting, hours worked is the measure favoured for the labour input to productivity calculations, but such data is only available for a sample of individuals and thus cannot be used in this context.

Development of labour productivity in the countries chosen has not diverged markedly over the period of time studied, as illustrated in Diagram 1. Most countries experienced growth in productivity after the economic downturn in the early 2000s, up until 2007 or

2008, when the great recession first manifested itself. Though not heavy in ICT maturity (or human capital), Danish productivity seems to have been less hit by this crisis and is the only series not turning down after 2008. The manufacturing industry (not reported separately here), which generally operates on a higher level of productivity than the service firms, was far more affected by the extensive fall in international demand and is a strong force behind the downturn.

**Diagram 1. Labour productivity patterns (Euro, thousands)**




Note: Labour productivity based on value added, adjusted for purchasing power and re-weighted with respect to sample size and number of employees.
Source: ESSLait dataset

The computation of capital (K) varies across countries: some use proper capital stocks and others book values. However, this is not considered a major problem since the capital variable goes into the regressions in its logarithmic form and is in this context only of interest for its marginal effect. All current prices are deflated by country-specific EUKLEMS/WIOD National Accounts based industry deflators, producer prices or investments indices.[10] As described in our Method section, we followed the mainstream approaches to productivity at firm level, by controlling for firm age (AGE) and age squared ($AGE^2$), with the latter recruited to control for non-linearity.

Educational attainment is measured strictly by formal qualifications. While these are not influenced by production values, they fail to capture skills acquired through learning by doing. A proxy including wages might have been able to seize informal skills. However, the general lack of analyses based on formal educational achievements not

[10] www.euklems.net and www.wiod.org.

only makes this angle far more intriguing but also allows one to make the sought-after split between different kinds of educational orientations. The problem of wages being closely related to production values is also avoided by this approach.

ICT-intensive human capital is approximated by post upper secondary education in mathematics, physics, engineering or information technology, based on two-digit international ISCED (International Standard Classification of Education) codes. In our estimation framework, we use the shares of ICT-intensive (HKITpct) and generally skilled (HKNITpct) human capital. As can be seen from Table 2, in all countries the proportion of high skilled employees with generic education is far larger than the proportion of employees with ICT-intensive higher education. One country that stands out in this comparison is Finland, which has the highest share of ICT-intensive human capital and the second highest share of generic highly skilled employees. The data also suggests that except in the United Kingdom, firms in all countries have considerably expanded their share of highly educated employees. This latter dynamic is particularly pronounced for non-ICT higher education profiles.

**Table 2. ICT-intensive and general highly-skilled human capital by industry (per cent)**

| **PS** | | **DK** | | **FI** | | **FR** | | **NO** | | **SE** | | **UK** | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *2001=t1, 2009=t2* | | *t1* | *t2* | *t1* | *t2* | *t1* | *t2* | *t1* | *t2* | *t1* | *t2* | *t1* | *t2* |
| Employees with ICT-intensive post upper secondary education (HKIT) | All firms | 3 | 4 | 7 | 9 | 1 | 3 | 3 | 4 | 3 | 5 | 5 | 6 |
| | Manufacturing | 3 | 3 | 8 | 11 | 0 | 2 | 2 | 2 | 2 | 3 | 5 | 5 |
| | Services | 4 | 5 | 8 | 9 | 1 | 4 | 4 | 5 | 3 | 7 | 5 | 6 |
| Employees with general post upper secondary education (HKNIT) | All firms | 5 | 8 | 9 | 15 | 8 | 12 | 12 | 18 | 9 | 14 | 8 | 8 |
| | Manufacturing | 4 | 5 | 5 | 8 | 8 | 12 | 8 | 11 | 6 | 8 | 5 | 6 |
| | Services | 6 | 9 | 13 | 18 | 7 | 15 | 15 | 18 | 9 | 15 | 11 | 10 |

Source: ESSLait dataset

Table 2 suggests that the take up of graduate employees has improved over time and that service firms seem to be the ones that make most use of highly skilled labour.

The aggregate productivity shocks described in the section on method are represented by dummy variables that hold changes in productivity over time and differences across industries fixed. Additionally, there are dummies used to control for firm-specific characteristics such as size, export experience and multinational affiliation. All variables are described in Table 3, including information on how they are sourced.

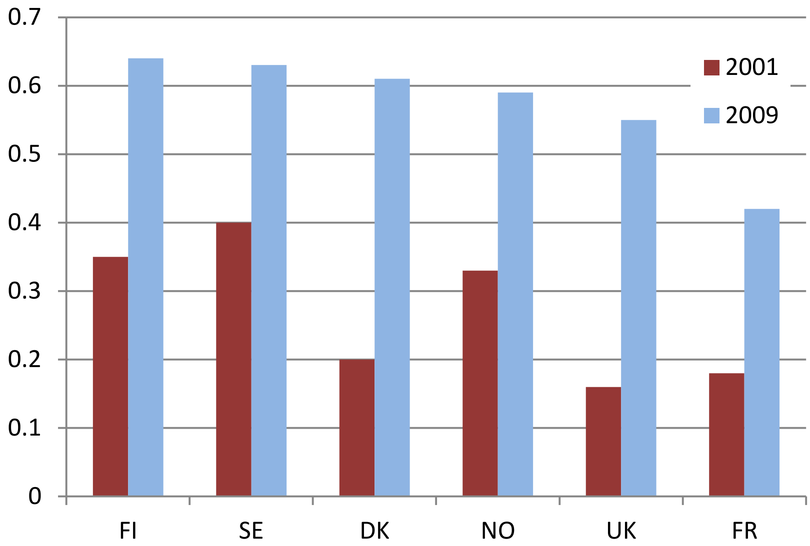
**Table 3. Variable description**

| ***Theoretical variable*** | ***Description*** | **Estimation variable** | **Description and Source** |
|---|---|---|---|
| *Y* | *Production* | **V** | Value added (PS) |
| *L* | *Labour* | **E** | Number of employees (PS) |
| *K* | *Capital* | **K** | Capital stock or book value (PS) |
| $S^l$ | *Shares of highly skilled labour* | **HKpct** | Proportion of employees with post upper secondary education (Education Register, Occupation Register or IS) |
| | | **HKITpct** | Proportion of employees with post upper secondary ICT-intensive education |
| | | **HKNITpct** | Proportion of employees with post upper secondary general education |
| *Z* | *Vintage* | **AGE** | Firm age (BR) |
| | | **AGE2** | Firm age squared (BR) |
| *X* | *ICT Maturity* | **BROADpct** | Proportion of broadband Internet-enabled employees in firms (EC) |
| | | **MOB** | Firm has mobile connection (EC) |
| $S^lX$ | Interaction term | **HKITBROAD** | Proportion of employees with ICT intensive post upper secondary education*proportion of broadband Internet-enabled employees |
| | | **HKNITBROAD** | Proportion of employees with non-ICT intensive post upper secondary education*proportion of broadband Internet-enabled employees |
| $D^c$ | *Firm characteristics* | **MNC** | Firm is multinational=1 (PS) |
| | | **EXP** | Firm is exporting =1 (VAT or International Trade) |
| | | **Size class** | Eight size classes* (PS, BR) |
| $D^f$ | *Aggregate productivity shock* | **Industry** | EUKLEMS 2-digit industry (BR) |
| | | **Time** | Year (PS, EC, IS) |

*The firms have been grouped in eight size classes: 0 if E=0; 1 if 0>E<10; 2 if 10≥E<20; 3 if 20≥E<50; 4 if 50≥E<100; 5 if 100≥E<250; 6 if 250≥E<500; 7 if E≥500. PS means production survey, BR is the business register, EC relates to the ICT usage and IS or CIS to the innovation activities in firms.

The proportion of broadband Internet-enabled employees (BROADpct) and whether the firm has mobile connections to Internet (MOB) are variables that may capture ICT-enabled organisational adjustment, or more clearly put, different phases of ICT maturity in firms. In certain contexts, both ICT variables could also be considered as proxies for process innovations: that is, new ways of handling firm operations as suggested, for instance, by Farooqui and Van Leeuwen (2008). Diagram 2 and Table 4 report the cross-country dynamics of both ICT maturity variables in our sample.

**Diagram 2. Broadband Internet-enabled employees (per cent)**




Source: ESSLait dataset

Finland, closely followed by Sweden, has the highest proportion of broadband Internet-enabled employees. These countries are also far ahead of the others in their use of mobile connections in firms. In 2009, France had the lowest proportion of broadband Internet-enabled employees in our sample. In 2001, the United Kingdom was at the lower end of usage, but it has caught up strongly, as has Denmark. Danish firms, however, seem to be relatively reluctant to embrace mobile connection equipment.

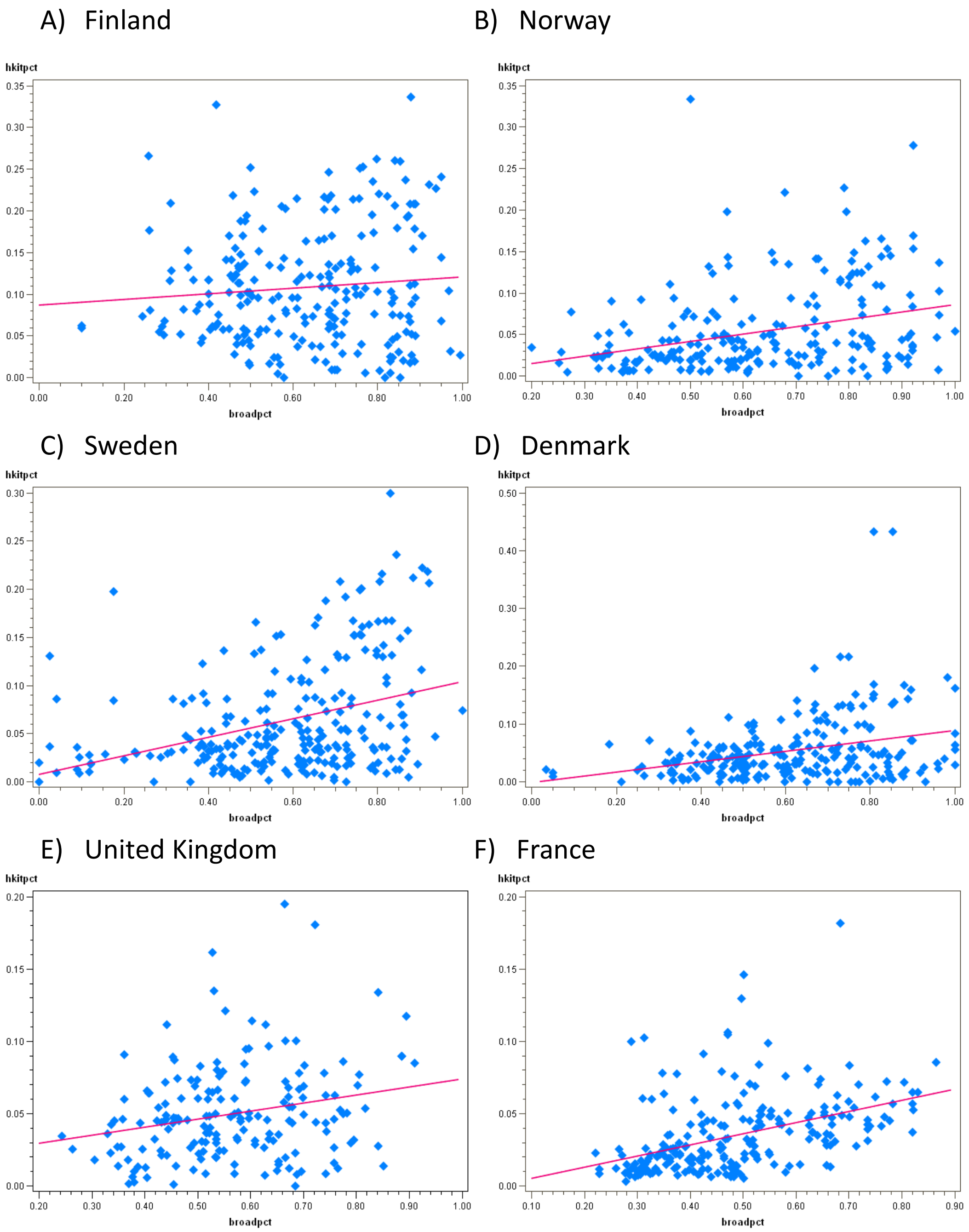
**Table 4. Firm ICT maturity (per cent)**

| 2009 EC | | DK | FI | FR | NO | SE | UK |
|---|---|---|---|---|---|---|---|
| Proportion of Broadband Internet-enabled employees (BROADpct) | All firms | 61 | 64 | 42 | 59 | 63 | 55 |
| | Manufacturing | 51 | 51 | 38 | 52 | 54 | 45 |
| | Services | 69 | 75 | 48 | 67 | 70 | 61 |
| Proportion of firms with mobile connections (MOB) | All firms | 54 | 81 | 59 | 62 | 68 | 64 |
| | Manufacturing | 55 | 82 | 61 | 63 | 68 | 62 |
| | Services | 55 | 81 | 61 | 60 | 68 | 65 |

Source: ESSLait dataset

The proportion of broadband Internet-enabled employees is greater in services firms than in manufacturing. However, availability of mobile connections hardly differs between the two groups of industries (Table 4). The willingness to adopt ICT early and the high level of ICT maturity in several of the Nordic countries may well be related to geographical conditions. In sparsely populated areas, a high level of ICT usage may increase job opportunities and facilitate efficiency in the labour market while in more densely populated areas, measures to increase firm efficiency may be seen as threats to jobs.

**Diagrams 3A-F. Correlation between ICT-intensive human capital and ICT maturity**




Note: Refers to manufacturing and services firms.
Source: ESSLait dataset

A strong linear correlation (close to 1 or -1) between the two major ICT variables would typically distort the accuracy of the parameter estimates in the regressions. Because of this we investigate the correlation for each country and for manufacturers and services firms together. Although there is some variation across the countries as is visible in Diagrams 3A-F, no strong correlations can be detected.

Despite many similarities, the industry structure in the countries investigated shows some differences. Norway's strength lies in its oil industry, as well as in retail trade and transportation. The latter is also important in Denmark and Finland. Sweden and Finland are both active in the forestry and ICT industries, while Denmark manufactures electronic equipment. Retail trade is common in the UK and France; whereas Sweden is committed to construction and wholesale. All six countries have high numbers of employees in the business services sector.

Beyond the difference between industries, in each country firms with high levels of highly skilled human capital tend to have more employees with access at work to broadband Internet or mobile connections. Typically, the same firms also have high capital, wages and productivity, as previously found by Doms et al (1997), Durbin (2004) and Galindo-Rueda and Haskel (2005).

### Estimations and discussion of results

The estimations are performed on the unbalanced pooled panels of firms, including the years 2001 to 2009, for Denmark, Finland, France, Norway, Sweden and the United Kingdom.

For all the countries studied, except the United Kingdom, stepwise regressions show stability over the different specifications in the effects on productivity of ICT-intensive human capital. ICT-intensive as well as generally skilled human capital boosts productivity although this happens to a greater or lesser extent depending on the country and the industry. Norway and Sweden experience the largest productivity bonuses as a result of increases in the proportion of ICT-intensive human capital in firms, followed by France and Finland. The United Kingdom and Denmark lag behind. A one per cent change in the proportion of ICT-intensive human capital increases firm productivity slightly more than proportionally in Norway. Capital and labour variables behave as expected, with clear positive effects on productivity, the former being particularly pronounced in the United Kingdom. Age variables are not especially important in any of the six countries. The results also indicate that being internationally active or affiliated usually is advantageous for firm productivity.[11]

The pattern of effects reveals two distinct tendencies. Productivity gains derived from ICT-intensive human capital appear to be larger than those derived from generally skilled human capital in some countries, and smaller in others. Thus, in France, although ICT-intensive human capital is statistically significant and high, its effect on productivity is less than that of generally skilled labour. A similar relationship can be observed in Danish firms, while the reverse is true for Norway, Sweden, Finland and the United Kingdom. Several of these results contradict those presented by Ilmakunnas and Maliranta (2005) and Brynjolfsson and Hitt (1997), who found that non-technological education gave the strongest productivity premium.

Our findings imply two things. Firstly, ICT-related assets may translate into productivity gains through a number of different channels. These channels may be associated, for instance, with the structure of the economy (services versus manufacturing) or with country-specific relations between different kinds of human capital and ICT maturity. Furthermore, the extent and quality of the human capital resources available for employment along with labour market regulations may interfere with the potential gains for firms from ICT-skilled employees.

Secondly, there may be different types of productivity effects from ICT, depending on the phase of ICT-enabled technological progress. We suggest a distinction between three such phases. In the *first phase* (1960s – late 1980s), characterised by initial ICT investments, accumulation of ICT capacities, and drastic organisational changes that required some time to be implemented, ICT impact on output was not large enough to be detected in statistical estimations. This is when the Solow paradox emerged. The *second phase* (1990s – early 2000) was characterised by a massive build-up of ICT capital (often referred to as the ICT bubble), and by significant rewards from the experimentation and learning during the previous phase. Many empirical studies suggest that the increase in productivity growth since 1990 is attributable to capital deepening (mainly in ICT equipment), and to efficiency gains in the production of ICT goods. [12] Finally, in the *third phase* (2000s), ICT leaders have already reaped the benefits of

[11] Coefficients of the age variables, international affiliation and experience are available but not reported here.
[12] See for instance, Jorgenson, Ho and Stiroh (2002, 2005 and 2008), Oliner and Sichel (2002) and Daveri (2003)

implementing cutting-edge technologies, and generally skilled employees can operate most ICT-enabled innovations without specialised training.[13] Thus, Basu et al. (2003), Basu and Fernald (2007) and Jorgenson et al (2008) show that ICT capital deepening and technological progress within the ICT-producing sector are reducing their effect on growth and that, symmetrically, the contributions from TFP and capital deepening in non ICT-producing sectors are becoming more important.

On the macro-level, this conclusion is supported, for instance, by the findings of Jorgenson et al (2008), who studied the sources of productivity and output growth from 1959 till 2006. They showed that the contribution of ICT to the average labour productivity in the US was highest in 1995-2000, while the contribution of labour quality was lowest in 1995-2000 and highest in 2000-2006. On the micro-level, Brynjolfsson and Hitt (1997) found that computer capital exhibited growing levels of investment and decreasing returns over the period of 1987-1991, and established that ICT’s contribution to output decreases over time. Eurostat (2012) points to a similar pattern, at least concerning simpler usages of ICT. Thus, in the third phase of ICT-enabled technological progress, it is not ICT investment per se that matters anymore, but the expertise and accumulated knowledge that allows firms to retain gains from the comparative advantages of ICT innovations. In our study, we capture this expertise using the ICT maturity variable.

When the ICT maturity variable (BROADpct) is added to the regressions the human capital effects decrease only slightly in all countries except the United Kingdom. The United Kingdom firms exhibit a distinct different pattern where the boost to productivity is reduced by almost a third when the ICT maturity is taken into account. Although significant and positive, the influence on productivity of broadband internet-enabled employees is generally smaller than the effect of human capital. This is particularly noticeable for Denmark and Finland.[14] The United Kingdom stands out as having the highest score on the importance of the ICT maturity variable for productivity. Nevertheless this is not the first time stronger effects from ICT have been reported for firms in the United Kingdom than in other countries. For instance, this was also a finding by Bloom et al (2010), who also discussed the underlying rigidity of the labour market as a factor that might affect the uptake of ICT.

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[13] See also the discussion of results reported in Table 8.

[14] Also estimated, but not reported here is a specification extended by MOB, the second ICT maturity variable in the shape of a dummy for mobile connections in firms, which reveals that these kinds of connections make little if any difference. Consecutively it has been left out in the regressions.

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

OLS estimations on unbalanced panel of firms

| PSEC 2001-09 | DK 1 | 2 | FI 1 | 2 | FR 1 | 2 |
|---|---|---|---|---|---|---|
| lnK | 0.081** | 0.081** | 0.086** | 0.086** | 0.170** | 0.166** |
| | 0.003 | 0.003 | 0.002 | 0.002 | 0.002 | 0.002 |
| lnE | 0.902** | 0.902** | 0.830** | 0.828** | 0.761** | 0.764** |
| | 0.013 | 0.013 | 0.010 | 0.011 | 0.005 | 0.005 |
| HKITpct | 0.509** | 0.501** | 0.688** | 0.630** | 0.740** | 0.656** |
| | 0.033 | 0.033 | 0.028 | 0.029 | 0.028 | 0.029 |
| HKNITpct | 0.707** | 0.698** | 0.659** | 0.601** | 1.100** | 1.021** |
| | 0.032 | 0.033 | 0.028 | 0.030 | 0.019 | 0.019 |
| AGE | | 0.002** | | 0.000 | | 0.000 |
| | | 0.001 | | 0.001 | | 0.000 |
| AGE2 | | 0.000** | | 0.000 | | 0.000 |
| | | 0.000 | | 0.000 | | 0.000 |
| BROADpct | | 0.029** | | 0.082** | | 0.145** |
| | | 0.009 | | 0.012 | | 0.007 |
| _EDF_ | 13662 | 13659 | 20750 | 20458 | 44440 | 44141 |
| _RSQ_ | 0.92 | 0.92 | 0.89 | 0.89 | 0.93 | 0.93 |

Note: Included but not reported are fixed time and industry effects as well as dummy variables for size class, international experience and affiliation. Robust standard errors are shown in grey. All results with ** are significant at the one per cent level and with * significant at five or ten per cent levels.
Source: ESSLait dataset

Overall, the results discussed here are in line with those of Blake and Lynch (1996), Rao et al (2002) and Niringiye (2010): that is, increases in the proportion of skilled human capital boost productivity. However, they also lend support to the observation of Iranzo et al (2008) that the kind of human capital seems to matter.

The high adoption level of ICT in Finland coincides with its rather small gains from ICT maturity as compared with ICT-intensive human capital. High ICT maturity could indicate that the benefits have already been reaped, that is, the country or industries have entered the third phase of ICT-enabled technological progress as described above. The Danish pattern shows similar tendencies to the Finish one, while Sweden and Norway, also heavy users, are still gaining from increases in ICT maturity as well as from ICT-intensive human capital, albeit more modestly from the former. Earlier work by Hagsten and Kotnik (2008) and Bartel et al (2007) also reflects this link to ICT maturity.

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

OLS estimations on unbalanced panel of firms

| PSEC 2001-09 | NO 1 | 2 | SE 1 | 2 | UK | 2 |
|---|---|---|---|---|---|---|
| lnK | 0.117** | 0.110** | 0.121** | 0.118** | 0.251** | 0.231** |
| | 0.002 | 0.002 | 0.002 | 0.002 | 0.005 | 0.005 |
| lnE | 0.921** | 0.908** | 0.870** | 0.871** | 0.734** | 0.768** |
| | 0.008 | 0.009 | 0.008 | 0.008 | 0.010 | 0.010 |
| HKITpct | 1.031** | 0.927** | 0.810** | 0.730** | 0.582** | 0.352** |
| | 0.031 | 0.032 | 0.030 | 0.031 | 0.055 | 0.054 |
| HKNITpct | 0.698** | 0.614** | 0.677** | 0.584** | 0.385** | 0.241** |
| | 0.020 | 0.022 | 0.029 | 0.030 | 0.035 | 0.035 |
| AGE | | 0.010** | | 0.015** | | 0.023** |
| | | 0.001 | | 0.002 | | 0.003 |
| AGE2 | | 0.000** | | 0.000** | | -0.001** |
| | | 0.000 | | 0.000 | | 0.000 |
| BROADpct | | 0.181** | | 0.150** | | 0.588** |
| | | 0.009 | | 0.010 | | 0.020 |
| _EDF_ | 33296 | 28680 | 27492 | 26543** | 14089 | 14086 |
| _RSQ_ | 0.91 | 0.91 | 0.93 | 0.93 | 0.75 | 0.77 |

Note: French estimates refer to the years 2001 and 2006-09. Included but not reported are fixed time and industry effects as well as dummy variables for size class, international experience and affiliation. Robust standard errors are shown in grey. All results with ** are significant at the one per cent level and with * significant at five or ten per cent levels.

Source: ESSLait dataset

A more detailed picture of how output is affected emerges when the manufacturing and services firms are studied separately, see Tables 6A and 6B. The strongest boost comes from the services firms, whose productivity seems to be slightly less dependent on kind of skilled human capital. On the other hand, the spread in estimates between the two groups of human capital is wider for manufacturers, particularly in France, Norway and Finland. These spreads reveal two distinct tendencies.  While Norway receives by far the largest productivity premium from ICT-intensive human capital, manufacturers in France react much more strongly to high general skills. Danish and Finnish services firms follow the French pattern and seem to reap more benefits from non-ICT-intensive human capital. The discrepancy in effects from ICT-intensive and generally skilled human capital is small for both manufacturing and services firms in Sweden.

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 they suggest that ICT-intensive human capital is particularly important because it makes better use of specific real capital inputs, while generally skilled human capital mainly contributes to productivity by promoting flexibility and the ability to generate spillover effects.

**Tables 6A and B. Direct effects on firm productivity from ICT-intensive human capital by industry**

OLS estimations on unbalanced panel of firms

| **A** | **Manufacturing** | | | | | |
|---|---|---|---|---|---|---|
| PSEC 2001-09 | DK | FI | FR | NO | SE | UK |
| lnK | 0.083** | 0.082** | 0.171** | 0.111** | 0.103** | 0.255** |
| | 0.006 | 0.004 | 0.004 | 0.005 | 0.005 | 0.011 |
| lnE | 0.925** | 0.908** | 0.780** | 0.846** | 0.952** | 0.836** |
| | 0.024 | 0.016 | 0.009 | 0.020 | 0.015 | 0.023 |
| HKITpct | 0.610** | 0.587** | 0.385** | 1.112** | 0.523** | 0.169** |
| | 0.110 | 0.061 | 0.137 | 0.105 | 0.088 | 0.087 |
| HKNITpct | 0.474** | 0.155** | 1.246** | 0.296** | 0.494** | 0.224* |
| | 0.093 | 0.067 | 0.044 | 0.067 | 0.083 | 0.085 |
| AGE | -0.001 | -0.001 | 0.000 | 0.004* | 0.017** | 0.030** |
| | 0.001 | 0.001 | 0.000 | 0.002 | 0.004 | 0.004 |
| AGE2 | 0.000 | 0.000 | 0.000 | 0.000* | -0.001** | -0.001** |
| | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| BROADpct | 0.018 | 0.054** | 0.183** | 0.172** | 0.136** | 0.547** |
| | 0.019 | 0.022 | 0.013 | 0.023 | 0.020 | 0.040 |
| _EDF_ | 4084 | 8055 | 15298 | 6696 | 7431 | 4518 |
| _RSQ_ | 0.92 | 0.90 | 0.94 | 0.90 | 0.94 | 0.76 |

| **B** | **Services** | | | | | |
|---|---|---|---|---|---|---|
| PSEC 2001-09 | DK | FI | FR | NO | SE | UK |
| lnK | 0.083** | 0.088** | 0.163** | 0.115** | 0.111** | 0.226** |
| | 0.003 | 0.003 | 0.002 | 0.002 | 0.002 | 0.005 |
| lnE | 0.887** | 0.785** | 0.764** | 0.915** | 0.879** | 0.759** |
| | 0.018 | 0.015 | 0.006 | 0.011 | 0.012 | 0.012 |
| HKITpct | 0.469** | 0.641** | 0.662** | 0.911** | 0.634** | 0.460** |
| | 0.037 | 0.034 | 0.032 | 0.036 | 0.035 | 0.074 |
| HKNITpct | 0.729** | 0.759** | 0.909** | 0.668** | 0.618** | 0.249** |
| | 0.037 | 0.035 | 0.024 | 0.025 | 0.035 | 0.040 |
| AGE | 0.004** | 0.001* | 0.002** | 0.013** | 0.019** | 0.023** |
| | 0.001 | 0.001 | 0.000 | 0.001 | 0.002 | 0.004 |
| AGE2 | 0.000** | 0.000 | 0.000 | 0.000** | 0.000** | -0.001** |
| | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| BROADpct | 0.033** | 0.090** | 0.156** | 0.195** | 0.150** | 0.593** |
| | 0.011 | 0.014 | 0.010 | 0.011 | 0.012 | 0.024 |
| _EDF_ | 8100 | 10138 | 20979 | 17758 | 13803 | 8723 |
| _RSQ_ | 0.91 | 0.89 | 0.92 | 0.91 | 0.93 | 0.77 |

Note: French estimates refer to the years 2001 and 2006-09. Included but not reported are fixed time and industry effects as well as dummy variables for size class, international experience and affiliation. Robust standard errors are shown in grey. All results with ** are significant at the one per cent level and with * significant at five or ten per cent levels.
Source: ESSLait dataset

Additionally, ICT may generate larger productivity impacts than would be predicted by considering the quantity of related inputs (human capital in this 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, the United Kingdom and Sweden in the proportion of ICT-intensive human capital (see section on descriptive data), it achieves the highest productivity gains from ICT intensive labour. ICT maturity behaves as for firms in general.

Mason and Firth (2004) conclude that a deficit in specialised skills would not only restrict adoption, but also limit the possible benefits of ICT. From the first sight, this does not seem to be exactly the case for the countries investigated here. The United Kingdom, which has a low proportion of highly skilled human capital among employees overall, has gained hugely from ICT maturity, while Finland, which operates at a higher level in both aspects, reacts only marginally to increases in ICT maturity. However, there are a number of possible explanations for this pattern. For example, the marginal utility of ICT maturity or skills may be higher in a low-ICT maturity environment. In the United Kingdom, where the human capital boost was clearly reduced when the ICT maturity variable was introduced, a simple explanation could be that ICT human capital and maturity (as measured in our study) to a certain extent act as substitutes, or that the ICT maturity is in fact a proxy for skills achieved outside the formal educational system. The United Kingdom pattern is not very obvious in any other country, and could conceivably stem from the particularities of its high degree of flexibility in the labour market where demand for labour may discriminate to a lesser extent between formally and informally achieved skills.

As suggested by Acemoglu (1998) and Gunnarsson et al (2004), ICT investments and human capital would be expected to complement each other. Indeed, using firm-level data for 2001-2005, Hagsten and Kotnik (2008) found that Swedish services firms in particular gained from a complementarity between human capital and broadband internet-enabled employees. However, in this study, we retested this hypothesis over a longer period (2001-2009) by introducing two interaction terms, (HKITBROAD) and (HKNITBROAD), allowing the proportion of employees with ICT-intensive or general post-upper secondary education to vary with the proportion of broadband Internet-enabled employees. The estimates presented in Table 8 show that in the longer time series the productivity boost is no longer apparent in Swedish firms. Instead, the Swedish services firms are joined by their Finnish and British counterparts and by Finnish manufacturers in experiencing productivity losses when ICT intensive human capital interacts with ICT maturity. Norwegian services are the only firms that gain from the interaction and this with generally skilled human capital operating through ICT maturity.

**Table 7. Indirect effects on firm productivity**

OLS estimations on unbalanced panel of firms

| PSEC | Manufacturing | | | | | | Services | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2001-2009 | DK | FI | FR | NO | SE | UK | DK | FI | FR | NO | SE | UK |
| lnK | 0.083** | 0.08**2 | 0.171** | 0.111** | 0.103** | 0.255** | 0.083** | 0.088** | 0.162** | 0.115** | 0.111** | 0.226** |
| | 0.006 | 0.004 | 0.004 | 0.005 | 0.005 | 0.011 | 0.003 | 0.003 | 0.002 | 0.002 | 0.002 | 0.005 |
| lnE | 0.925** | 0.907** | 0.780** | 0.845** | 0.952** | 0.835** | 0.887** | 0.785** | 0.763** | 0.915** | 0.879** | 0.759** |
| | 0.024 | 0.016 | 0.009 | 0.020 | 0.015 | 0.023 | 0.018 | 0.015 | 0.006 | 0.011 | 0.012 | 0.012 |
| HKITpct | 0.657** | 0.878** | 0.596* | 1.295** | 0.573* | 0.231 | 0.510** | 0.847** | 0.617** | 1.023** | 0.884** | 0.882** |
| | 0.159 | 0.123 | 0.265 | 0.240 | 0.217 | 0.163 | 0.059 | 0.106 | 0.069 | 0.115 | 0.127 | 0.175 |
| HKNITpct | 0.551** | 0.082 | 1.397** | 0.153 | 0.449* | 0.293* | 0.751** | 0.731** | 1.066** | 0.583** | 0.491** | 0.237** |
| | 0.131 | 0.159 | 0.061 | 0.136 | 0.194 | 0.146 | 0.059 | 0.082 | 0.040 | 0.053 | 0.083 | 0.063 |
| AGE | -0.001 | -0.001 | 0.000 | 0.004* | 0.017** | 0.030** | 0.004** | 0.001* | 0.002** | 0.013** | 0.019** | 0.023** |
| | 0.001 | 0.001 | 0.000 | 0.002 | 0.004 | 0.004 | 0.001 | 0.001 | 0.000 | 0.001 | 0.002 | 0.004 |
| AGE2 | 0.000 | 0.000 | 0.000 | 0.000* | -0.001** | -0.001** | 0.000** | 0.000 | 0.000 | 0.000** | 0.000** | -0.001** |
| | 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 | 0.035 | 0.090** | 0.231** | 0.164** | 0.136** | 0.567** | 0.041** | 0.098** | 0.190** | 0.184** | 0.147** | 0.611** |
| | 0.027 | 0.029 | 0.017 | 0.027 | 0.024 | 0.047 | 0.015 | 0.018 | 0.012 | 0.013 | 0.014 | 0.027 |
| HKITBROAD | -0.096 | -0.417** | -0.325 | -0.233 | -0.063 | -0.111 | -0.063 | -0.226* | 0.043 | -0.118 | -0.266* | -0.544* |
| | 0.220 | 0.153 | 0.362 | 0.273 | 0.252 | 0.243 | 0.071 | 0.111 | 0.080 | 0.121 | 0.131 | 0.204 |
| HKNITBROAD | -0.140 | 0.075 | -0.338** | 0.195 | 0.058 | -0.146 | -0.036 | 0.029** | -0.242** | 0.110* | 0.151 | 0.008 |
| | 0.165 | 0.186 | 0.088 | 0.164 | 0.229 | 0.234 | 0.072 | 0.093 | 0.049 | 0.061 | 0.093 | 0.096 |
| _EDF_ | 4082 | 8053 | 15296 | 6694 | 7429 | 4516 | 8098 | 10136 | 20977 | 17756 | 13801 | 8721 |
| _RSQ_ | 0.92 | 0.90 | 0.94 | 0.90 | 0.94 | 0.76 | 0.91 | 0.89 | 0.92 | 0.91 | 0.93 | 0.77 |

Note: French estimates refer to the years 2001 and 2006-09. Included but not reported are fixed time and industry effects as well as dummy variables for size class, international experience and affiliation. Robust standard errors are shown in grey. All results with ** are significant at the one per cent level and with * significant at five or ten per cent levels.
Source: ESSLait dataset

At first sight these results seem at odds with the expectation that ICT-specific human capital and ICT maturity should complement each other in boosting productivity. However, once again, this apparent contradiction may be resolved on the supposition that the studied countries differ in their phase of ICT development. A non-significant estimate could indicate either that there is still some catching up to do before payback can be expected, or that the benefits stage has already passed. Alternatively, even if the particular measure of ICT maturity investigated here affects most firms to a certain degree, it may no longer capture cutting edge technology and the specialised education required for its use. This means that the full preconditions for a strong indirect effect may no longer be present.

So far, the discussion has revolved mainly around the actual rather than the potential impact on productivity of ICT-intensive human capital and ICT-enabled organisational adjustment. At the same time, Bloom et al (2010) and Forth and Mason (2004), for instance, clearly point to conditions that could hold back possible benefits. Visual inspection side by side of the intensities and the impacts of ICT variables presented in Table 8, gives no clear indication of discrepancies between actual and potential impacts, but reveals that high levels of ICT maturity coincide with the stronger impact only in Sweden, while in Norway, Finland and France maturity and impact go in the opposite directions.

**Table 8. Intensities and impacts of the ICT-intensive assets**

| Intensity | | | | Impact | | | |
|---|---|---|---|---|---|---|---|
| HKITpct | | BROADpct | | HKITpct | | BROADpct | |
| FI | 10 | FI | 64 | NO | 0.927 | **UK** | 0.588 |
| UK | 6 | SE | 63 | SE | 0.730 | **NO** | 0.181 |
| SE | 5 | DK | 61 | FR | 0.656 | SE | 0.150 |
| NO | 4 | **NO** | 59 | FI | 0.630 | **FR** | 0.145 |
| DK | 4 | **UK** | 55 | DK | 0.501 | FI | 0.082 |
| FR | 3 | **FR** | 42 | UK | 0.338 | DK | 0.029 |

Note: All estimates are significant (Tables 5A and B).
Sources: ESSLait dataset

Although the estimations suggest that the direction of impact of both ICT human capital and ICT maturity is generally the same, there is some variation in their magnitude both between industries and across countries. This could reflect natural dissimilarities in the needs of firms, but might also indicate that the effect of ICT-intensive factors of production on firm output is not always reached to its full aptitude. Typically, a gap between actual and potential impact of ICT-specific human capital may arise from difficulties in recruiting human resources. These difficulties could originate from an excess demand for or insufficient supply of specific skills, or from a complex legal framework that creates bottlenecks in the labour market. For instance, we may assume that the pool of ICT-intensive human capital available to firms consists of a combination of the ICT specialists who are unemployed and those employed in the public sector (which is large in several of the countries sampled here). Without a reserve the average proportion of ICT-intensive human capital cannot be increased in firms in the short run.

To pursue our conjecture on the possible existence of a gap between actual and potential impact we compare two macro variables, a measure of labour market rigidity, and the proportion of highly educated ICT specialists among the currently unemployed and among public sector employees – against the set of ICT-specialised human capital impact indicators (see Table 9).[15]

**Table 9. Impact of ICT-intensive human capital on productivity, labour market regulation, and potential reserves of ICT-intensive human capital**

| Impact of HKITpct | | Employment regulation | | Reserve of ICT specialists % | |
|---|---|---|---|---|---|
| **NO** | 0.927 | UK | 1.198 | **NO** | 1.59 |
| **SE** | 0.730 | DK | 2.135 | **SE** | 1.51 |
| FR | 0.656 | FI | 2.183 | DK | 0.97 |
| FI | 0.630 | **NO** | 2.333 | UK | 0.95 |
| DK | 0.501 | FR | 2.431 | FI | 0.87 |
| UK | 0.338 | **SE** | 2.612 | FR | 0.53 |

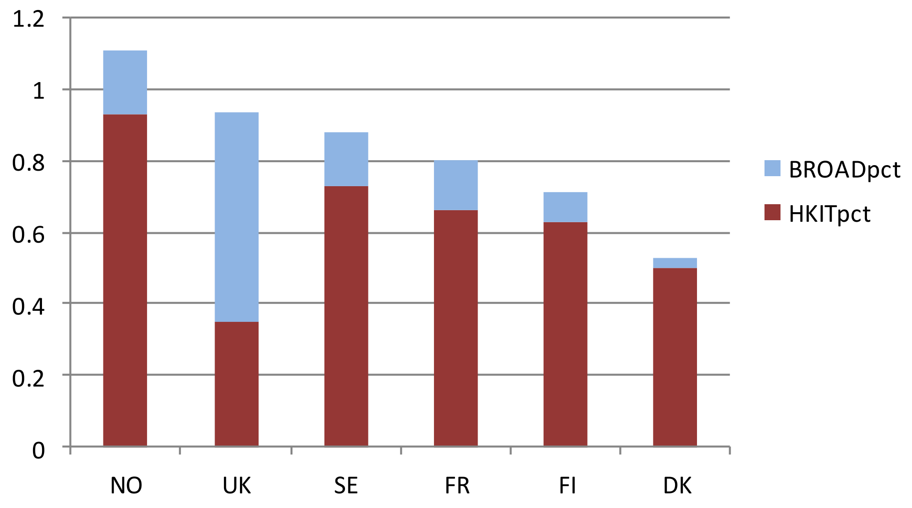
Note: Estimates of the ICT impact on productivity are taken from Tables 5A and 5B, the second specification Reserves of ICT specialists are calculated using the EU LFS data for 2001-2009, as the yearly average of the shares of those with ICT tertiary education among (a) the unemployed and (b) those employed in the public sector. Labour market regulation in each country is measured as the 2001-2009 average of the OECD employment protection summary indicator "Strictness of employment protection – individual dismissals (regular contracts)", which incorporates 8 data items. A higher value means stricter regulation.
Sources: ESSLait Dataset, OECD and EU LFS.

Labour market rigidity is approximated by the OECD employment protection index, where lower values mean fewer regulations.[16] What is most striking is that the country with the highest flexibility in its labour market, the United Kingdom, also gains less in output from ICT-intensive human capital; while Norway and Sweden – the countries whose productivity is most highly affected by ICT-specific human capital – are among the countries with the highest employment protection indicators in our sample. Notable is also the fact that the United Kingdom firms seem to reap by far the largest benefits from the ICT maturity variable, reflecting the ICT-enabled organisational adjustment. This is illustrated in Diagram 4, from which it is also obvious that when the two ICT impact indicators are considered together, the pattern across countries changes.

[15] Both these variables go beyond what is possible to include in our firm-level estimation of ICT impacts.

[16] See Venn (2009) and OECD Indicators of Employment Protection.

**Diagram 4. Impact of ICT-intensive human capital and ICT maturity on firm productivity**




Source: ESSLait dataset

Possibly, this might indicate that firms in countries with flexible labour markets can not only make organisational adjustments (which are typically labour-saving) more freely but also benefit better from ICT maturity. In countries with rigid labour markets it may be the case that it is easier to increase the proportion of ICT-skilled employees to boost firm performance, given there is a reserve available to source from. According to our calculations, Sweden and Norway have the largest available reserves for potential employment in the private sector, in combination with the most regulated labour markets.

As clearly revealed, the factors or structures that may underlie the potential gains of ICT-intensive human capital are far from exhausted by our discussion, and warrant further research.

## Concluding remarks

There are still computers everywhere, and the productivity gains they bring are now clearly visible. Although nowadays these returns may result more from how computers are connected, organised or used than from just the pure possession of them. However, part of the Solow paradox remains; and in this paper we have attempted to cast more light on how the often neglected ICT-intensive human capital fits into the picture, both on its own and together with ICT maturity in firms. Our findings will also add an extra dimension to the various EU 2020 initiatives, and maybe most specifically to the EU Digital Agenda, which surprisingly enough does not stress different kinds of human capital despite the strong emphasis on the potential effect on growth unleashed by the rapid progress in information technologies.

Our estimations indicate that increases of ICT-intensive human capital as well as ICT maturity mainly transform into positive effects on firm productivity in Denmark, Finland, France, Norway, Sweden and the United Kingdom. However, the strength of the effect seems to vary according to the industry and type of skill and, to a certain degree, by country.

Generally, the impact on firm performance is driven by services firms, but this does not mean that the effect on manufacturers is negligible. Norway and Sweden have the highest productivity rewards from ICT-intensive human capital while France and Denmark have benefitted more from generally skilled human capital. Without doubt, the United Kingdom is the country that has been most affected by improvements in the level of ICT maturity in firms.

The channel through which ICT-intensive human capital translates into productivity gains seems to be narrower than for generally skilled human capital, and the potential impact on productivity of the former may not be fully achieved until the real capital setting is as specific as the human capital. The “right” kind of human capital is particularly important for manufacturers. Services firms are more indifferent to the field of specialisation of their employees. Here, productivity effects from generally skilled human capital may instead stem more from its high level of flexibility and its ability to generate spillover effects, than from narrowly specialised human capital.

The literature emphasises the complementarity between skills and ICT. Although the direct effects on productivity in our study do not contradict the existence of such indirect impacts, the results display a certain disharmony. In the United Kingdom, human capital and ICT maturity seem to substitute rather than to complement each other. Norwegian services firms are the only ones to gain from indirect effects, and then only when generally skilled human capital operates through ICT maturity. Otherwise, when found, the complementarity reduces productivity, particularly for ICT-intensive human capital. This may signify that the countries in our sample are at different ICT maturity stages or that their prospects of channelling ICT-intensive human capital into efficient firm performance vary. Another underlying reason behind the lack of favourable complementarity could be that our chosen measure of ICT maturity is itself no longer sufficiently advanced to measure the indirect effect of ICT-intensive human capital on productivity.

In attempting to provide a more in-depth explanation of the differences across countries, we have considered the possibility that there is a gap between the actual and potential impact of ICT-intensive human capital on productivity, and have suggested the gap may stem from bottlenecks arising in the labour market.

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