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How Important are ICT and R&D Investments for Value Added in the Swedish Business Sector?

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Abstract

Since the mid-1990s value added has grown faster in the Swedish business sector than in the business sector of most other OECD countries. We investigate the association between ICT and R&D capital and value added in the Swedish non-farm business sector. By estimating neoclassical production function models on data for 47 different industries for the period 1993–2012 we show that ICT and R&D capital are significantly associated with value added for most specifications. When controlling for economic shocks the results show that on average, if ICT capital increases by 10 percent, value added increases by 1.8 percent. We also divide ICT capital into hardware and software capital. To our knowledge, this distinction has not been made in any previous study at the industry level. In this case only the estimated elasticity of software is significantly different from zero. One possible explanation could be that all industries invest in hardware, but only the ones that successfully invest in and implement software enjoy positive effects from ICT.

JEL *Codes*: O14; O32; O33; O47

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1. Introduction

Since the mid-1990s both value added and productivity have grown rapidly in the Swedish business sector. *Figure 1* shows economic growth in the non-farm business sector in 15 OECD countries in 1995–2010.[1] Sweden had the third highest value added growth rate, averaging 3.7 percent. Only South Korea and the Czech Republic grew more rapidly. Thus, since the mid-1990s the Swedish business sector has outperformed most other industrialized countries. How can this favorable development be explained?

For a long time investments in information and communications technology (ICT) and R&D have been emphasized as important for technical change and economic growth (e.g., Schumpeter 1942; Nelson 1959; Brynjolfsson and McAfee 2014). A number of studies have found evidence that the increase in the US growth rate after 1995 was driven by ICT investments (Oliner and Sichel 2000; Stiroh 2002a; Jorgenson et al. 2008). Together with the US and the UK, Sweden had one of the largest shares of ICT investments in total investments in the 2000s (OECD 2015b). Research also shows that investments in intangible assets through R&D are important for growth in value added and productivity (Corrado et al. 2009; Marrano et al. 2009). Sweden has also had higher R&D investments as a share of GDP compared to most other countries (OECD 2015a).

Given the high rates of aggregate ICT and R&D investments in Sweden it is of particular interest to explore whether such investments are associated with higher value added. This would suggest that ICT and R&D investments are economically justified. It would also suggest that countries with a similar industry structure could benefit from investing more in ICT and R&D. Therefore, we investigate whether ICT and R&D capital is positively associated with the level of value added across Swedish industries in 1993–2012. Moreover, we distinguish between two types of ICT capital – hardware and software – and explore their respective links to the level and growth of value added. More specifically, we investigate the following questions:

[1] Countries are included based on data availability. The industry classification is based on ISIC rev 4 and real estate activities are excluded.

- Is there a positive and significant association between high levels of ICT and R&D capital and value added at the industry level?
- Does the effect of ICT hardware differ from the effect of ICT software?
- Are there differences between manufacturing and service industries?
- Does the effect vary over time?

We show that ICT and R&D capital are significantly associated with value added for most specifications. An increase of ICT capital by 10 percent is associated with an increase in value added by 1.8 percent. The estimated elasticity for R&D capital in the pooled regressions is 0.11, but it is only significant at the 10 percent level. The elasticity is larger and the association stronger when we control for fixed effects.

We also divide ICT capital into hardware and software capital. To our knowledge, this distinction has not been made in any previous study at the industry level. In this case only the estimated elasticity of software is significantly different from zero. One possible explanation could be that all industries invest in hardware, but only the ones that successfully invest in and implement software enjoy positive effects from ICT.

The paper is organized as follows. In Section 2 we summarize findings from earlier research and position our study in the literature. In Section 3 we present the methodological framework, in Section 4 we describe the data, and in Section 5 we specify the model. Section 6 presents the results and Section 7 concludes.

2. Related Literature

OECD (2009a, p. 90) defines ICT as products "intended to fulfil or enable the function of information processing and communications by electronic means, including transmission and display". The economic impact of ICT has been extensively debated since the 1980s when Nobel Laureate Robert Solow famously remarked "You can see the computer age everywhere but in the productivity statistics" (Solow 1987, p. 36). The 1990s productivity

boom in the US and several other developed countries was linked to investment in ICT (Oliner and Sichel 2000; Van Reenen et al. 2010).

Based on growth accounting Oliner and Sichel (2000) found that ICT accounted for 1.45 percentage points of the 2.57 percent growth rate per annum of labor productivity in the US business sector in 1996–1999. Gordon (2000) was skeptical of these findings. He asserted that the productivity revival in the US was primarily driven by exceptionally rapid productivity growth in the production of computer hardware, peripherals and telecommunications equipment, while productivity growth in the rest of the economy remained sluggish. But as more data became available, it became increasingly evident that the productivity effects of ICT were substantial in most industries (Stiroh 2002a; Jorgenson et al. 2008). Byrne et al. (2013) showed that the relative contribution of ICT to labor productivity growth remained high in 2004–2012, i.e., after the productivity growth slowdown in the US.

While the rate of productivity growth increased sharply in the US after 1995, the growth rate remained sluggish in many countries in Western Europe (van Ark et al. 2008). Both ICT capital deepening and total factor productivity (TFP) increased more slowly in Europe compared to the US. van Ark et al. (2008) found that the productivity slowdown in Europe was primarily caused by slower TFP growth in services. One exception was Sweden, where the growth rates of value added and productivity were among the highest in Western Europe.

Based on growth accounting studies alone one cannot establish a clear link between ICT investments and labor productivity growth. However, there are also a number of econometric studies that link investment in ICT to growth in value added and productivity. Gust and Marques (2004) found a strong relationship between the GDP share of ICT production and labor productivity growth in 13 OECD countries for the period 1992–1999. Niebel (2014) found a positive relationship between ICT capital and GDP growth for 59 countries in the 1995–2010 period.

Furthermore, a number of studies explore the cross-country link between specific ICT capital and productivity growth. Röller and Waverman (2001) found a significant relationship between telecommunications infrastructure and aggregate output based on 21 OECD countries in 1971–1990. They found that about one third of economic growth could be attributed to telecommunications after controlling for simultaneity and country specific fixed effects. Likewise, Gruber and Koutroumpis (2011), based on data for 192 countries, found that investment in telecommunications infrastructure contributed 0.20 percentage points to economic growth in high income countries in 1990–2007.

As more micro data have become available, the number of studies estimating the impact of ICT at the firm level has increased. According to Van Reenen et al. (2010) most firm-level studies find a positive and significant association between ICT and productivity and value added. Based on firm-level data Brynjolfsson and Hitt (2003) found that ICT investment had a lagged effect on the growth of value added and TFP. They argue that it takes several years before the full growth contribution of ICT materializes.

The association between ICT capital and the levels of productivity and value added has been thoroughly investigated based on industry level data. For the US, Stiroh (2002a) found that ICT intensive industries experienced an accelerated productivity growth in 1995–2000 compared to 1987–1995. The growth differential to other industries was approximately 2 percentage points. Moreover, based on industry data for eighteen OECD countries Spiezia (2012) showed that the average contribution of ICT varied between 0.3 and 1.0 percentage points depending on country. ICT investments were divided into three types: computer equipment, communications equipment and software. In all countries except Finland and Japan computer equipment capital accounted for the largest share of the total ICT contribution.

Basu and Fernald (2007) found that with long time lags, ICT capital growth was positively associated with the industry TFP acceleration. Moreover, O'Mahony and Vecchi (2005) used industry data to show a positive return of ICT capital on output growth based on a dynamic panel data approach. Dahl et al. (2010) used panel data for seven EU countries and found that

European industries that were relatively ICT intensive before 1995, outperformed the other industries post-1995 in terms of both labor productivity and TFP growth.

Stiroh (2002b) used panel data to analyze the direct effect from the change in ICT capital on output in the US. He found a negative association between ICT capital deepening and output. One explanation for this unexpected result could be that the analysis was based solely on data for manufacturing for the period 1984–1999. Based on an updated dataset with a more detailed industry breakdown and the addition of service sectors, Stiroh (2005) found positive correlations between ICT and gross output. However, the ICT coefficients were not significant for all specifications. Nonetheless, the conclusion that ICT played a crucial role for the US productivity revival after 1995 is upheld, although some caution is called for regarding exactly how important ICT has been for US economic growth.

According to the Frescati Manual (OECD 2002, p. 30), R&D is defined as "creative work undertaken on a systematic basis in order to increase the stock of knowledge, including knowledge of man, culture and society, and the use of this stock of knowledge to devise new applications". While there is substantial evidence that ICT capital has a positive impact on value added and economic growth, the same is true for R&D. Both studies based on growth accounting and econometric estimations have found that R&D contributes to value added and productivity (McMorrow and Röger 2009; Hall et al. 2009). Moreover, estimates based on industry data are generally quite consistent with those obtained from firm data (Hall et al. 2009).

Based on growth accounting estimates Griliches (1991) found that more than half of US TFP growth was attributable to R&D. Moreover, Edquist (2011a) estimated that R&D accounted for nearly 13 percent of labor productivity growth in the non-farm business sector in Sweden in 1995–2000. In general, the elasticity of R&D tends to lie between 0.10 and 0.20 based on econometric estimates of cross sectional data (McMorrow and Röger 2009). Thus, on average a 10 percent increase in R&D capital services is associated with an average productivity increase of 1–2 percent.

The R&D research literature has also identified spillovers from R&D. Thus, R&D undertaken in one firm can impact positively on value added in other firms in the same industry. Griffith et al. (2001) found that R&D played a role in the convergence of TFP levels within industries across 12 OECD countries. Hence, R&D stimulates growth both directly through innovation and indirectly through technology transfer. There is also a comprehensive literature investigating the spillover effects from public spending on R&D (Salter and Martin 2001; Goodridge et al. 2015). However, we will focus primarily on the direct effects of R&D.

Until 2013 R&D was not capitalized in the national accounts, i.e., it was treated as a current expense. Since September 2014, when Statistics Sweden began to use the System of National Accounts 2008, R&D is treated as investment (see SNA 2009). This strengthens the case for and facilitates the inclusion of R&D when estimating production functions econometrically.

In summary, the literature suggests that ICT capital has been important growth at the aggregate, industry and firm-levels. Moreover, the same is true for R&D, which also seems to stimulate growth through technology transfer.

3. Methodology

3.1 The standard neoclassical production function

Our framework is based on the neoclassical production function model (Stiroh 2002b; 2005), where a gross output production function relates output to labor, capital, intermediate inputs and TFP:[2]

$$Y_{i,t} = A_{i,t} f_{i,t}(K_{ICT,i,t}, K_{N,i,t}, R_{i,t}, L_{i,t}, M_{i,t}) \qquad (1)$$

where $Y_{i,t}$ is real gross output, K_{ICT} is ICT related capital and K_N is non-ICT capital, R is R&D capital, L labor input, M is intermediate inputs and A is Hicks-neutral TFP, all for industry (i)

[2] Value added is used instead of gross output to specify the model (see section 5). This implies that intermediate inputs are excluded as an independent variable.

at time (*t*). Assuming an augmented Cobb-Douglas production function (Cobb and Douglas 1928), we have the following equation:

$$Y_{i,t} = A_{i,t} K_{ICT,i,t}^{\beta_{ICT}} K_{N,i,t}^{\beta_N} R_{i,t}^{\beta_R} L_{i,t}^{\beta_L} M_{i,t}^{\beta_M} \quad (2)$$

By taking natural logarithms of equation (2):

$$\ln Y_{i,t} = \beta_{ICT} \ln K_{ICT,i,t} + \beta_N \ln K_{N,i,t} + \beta_R \ln R_{i,t} + \beta_L \ln L_{i,t} + \beta_M \ln M_{i,t} + \ln A_{i,t} \quad (3)$$

where β represents the output elasticity of each input.

3.2 Capital services

There are different types of capital such as buildings, vehicles and software. Statistics Sweden publishes figures for these different types of capital in terms of capital stocks. However, using capital stocks when analyzing the impact of capital is likely to be misleading, since long-lived types of capital, such as buildings, get too high a weight compared to short-lived assets, such as software. According to Jorgenson and Griliches (1967) the theoretically correct way to measure capital in a production function is by measuring capital services. These services can be estimated by the rental payments that a profit maximizing firm would pay when renting its capital.

In order to estimate capital services it is necessary to estimate the capital stock. We estimate the capital stock based on the perpetual inventory method (PIM).[3] The different types of capital included in the calculations are listed in *table 1*.[4] By assuming a geometric depreciation pattern the capital stock (K), for each type of capital (*s*) at time (*t*), can be derived according to the following formula:

$$K_{s,t} = (1 - \delta_{s,t}) K_{s,t-1} + I_{s,t} \quad (4)$$

[3] For a detailed description, see OECD (2009b).
[4] The capital stocks of (1) Cultivated biological resources and (2) Other intellectual property products were excluded. These two types of capital only accounted for 0.7 percent of total investments in 2012.

where $K_{s,t}$ is the capital stock, $\delta_{s,t}$ is the depreciation rate and $I_{s,t}$ is real investment. Depreciation rates are from the EU KLEMS database (EU KLEMS 2011). The industry structure in EU KLEMS differs somewhat from the classification used by Statistics Sweden (i.e. ISIC rev. 4). Thus, for a few industries that are not included in EU KLEMS approximations were made. *Table 2* shows the depreciation rates used for each type of capital and industry.

Based on the estimates of the capital stocks and investment price indexes (p^I) provided by Statistics Sweden it is possible to calculate the internal rate of return for each industry (i):

$$irr_{i,t} = \frac{p_t^K K_t + \sum_s (p^I_{s,i,t} - p^I_{s,i,t-1}) K_{s,i,t} - \sum_s p^I_{s,i,t} \delta_{s,i,t} K_{s,i,t}}{\sum_s p^I_{s,i,t-1} K_{s,i,t}} \quad (5)$$

where the first term $p_t^K K_t$ denotes overall capital compensation in the economy. By assuming constant returns to scale it can be estimated as value added in current prices minus labor compensation. $p^I_{s,i,t}$ is the investment price of capital s in industry i at time t, $K_{s,i,t}$ is the capital stock, and $\delta_{s,i,t}$ is the depreciation rate. The internal rate of return varies across industries but not across types of capital (s), as the internal rate of return will be equalized across assets in a competitive market.

The internal rate of return ($irr_{i,t}$) is then used to derive the rental prices ($p^K_{s,i,t}$) of each capital type (s) in industry i. The rental price equals the price at which the investor is indifferent between buying and renting the capital good in the rental market. The rental price can be estimated as follows:

$$p^K_{s,i,t} = p^I_{s,i,t-1} irr_{i,t} + \delta_{s,i,t} p^I_{s.i,t} - (p^I_{s,i,t} - p^I_{s,i,t-1}) \quad (6)$$

where $irr_{i,t}$ is the internal rate of return, $\delta_{s,i,t}$ is the depreciation rate and $p^I_{s,i,t}$ is the investment price of asset s. Thus, eq. (7) shows that the rental price is determined by the nominal rate of return, the rate of economic depreciation and the asset-specific capital gain.

Rental prices can be used to calculate capital compensation for each type of capital and industry:

$$c_{s,i,t} = p^{K}_{s,i,t} K_{s,i,t} \quad (7)$$

Finally, the change in capital services for industry *i* is obtained as follows:

$$\Delta \ln K_{i,t} = \sum_s \tilde{v}_{s,i,t} \Delta \ln K_{s,i,t} \quad (8)$$

where the weight $\tilde{v}_{s,i,t}$ is the two-period average share of compensation by each type of capital in the total value of capital compensation for all industries:

$$\tilde{v}_{s,i,t} = \frac{1}{2}\left(v_{s,i,t} + v_{s,i,t-1}\right) \quad (9)$$

$$v_{s,i,t} = \frac{c_{s,i,t}}{\sum_s c_{s,i,t}} \quad (10)$$

This method is used to calculate capital services for ICT capital and non-ICT capital and R&D.

4. Data

The data used are based on the national accounts provided by Statistics Sweden (2015) and cover 50 industries for the period 1993–2012. *Table 3* presents the different industries following the international standard for industry classification (ISIC 2008). The following three industries had to be excluded due to missing data: Activities auxiliary to financial service insurance activities (ISIC K66), Real estate activities with own or leased property (ISIC 68A), and Health activities (ISIC P86). Thus, the regressions are based on 47 industries.

Output is measured as value added and labor input as hours worked. Value added estimates are based on double deflation and are expressed in real terms in prices of the year 1993, the starting year of the period examined. There are both advantages and disadvantages in using value added instead of gross output (Stiroh 2005). One advantage of using value added is that nominal value added sums to GDP. A disadvantage would be that value added requires stricter assumptions of perfect competition (Basu and Fernald 1995).[5]

Capital input data are based on estimates of capital services. Capital services are preferred to capital stock data, since that measure accounts for the substitution between assets with different marginal products. As a result, the weights will not be too high for long lived assets such as industrial real estate. Statistics Sweden does not provide any official estimates of capital services for industries. Capital services were estimated based on data on investment, capital stock and investment price for the different industries provided by Statistics Sweden (using the methodology presented in section 3.2). Depreciation rates are from EU KLEMS (2011) and Statistics Sweden.

The following types of capital were included: dwellings, other buildings, transportation equipment, ICT hardware, other machinery and inventories, R&D, software (see *table 1*). The depreciation rates used for all types of capital except ICT hardware and R&D are based on EU KLEMS (2011). The industry structure in EU KLEMS (2011) differs from the industry structure used here (i.e. ISIC rev. 4). For software and dwellings there are no differences across industries in depreciation rates in the EU KLEMS database. For other buildings, transportation equipment and other machinery and inventories the depreciation rates for different industries were translated into the new industry classification. In some cases approximations were made.

[5] Value added is defined as gross output minus intermediate inputs. This implies that one must know the marginal products of these intermediate inputs. Real value added is constructed assuming that these marginal products are observable from factor payments to intermediate goods. With imperfect competition the marginal product exceeds the factor payments. Thus, with imperfect competition value added can lead to spurious findings. On the other hand, contestable competition may suffice; the risk of entry may be enough to deter incumbents from exploiting their market power and maintain dynamic efficiency (Audretsch, Baumol and Burke 2001).

ICT hardware includes both communications and computer equipment. According to EU-KLEMS the depreciation rates between these differ. Statistics Sweden only publishes data for the aggregate of these two types of assets. Therefore the depreciation rates in EU KLEMS have been weighted based on the average share of each type of capital in total gross fixed capital formation (GFCF). The data on GFCF for communications and computer equipment separately was made available by Statistics Sweden. Finally, the depreciation rate used for R&D has been set to 16.5 percent and should be close to the one used by Statistics Sweden. *Table 2* shows the depreciation rates for each type of capital and industry.

Capital services were calculated for ICT, non-ICT and R&D. Since 2014 R&D is capitalized in the national accounts. This makes it possible to use R&D capital services when estimating production functions at the industry level. Moreover, ICT capital services were divided into the components hardware and software. Based on the calculations of capital services, indexes were constructed by using the capital stock in 1993 prices. A similar index was created for value added.[6]

5. Specification of the model

The specification of the econometric model is based on the production function in section 3. The dependent variable is value added. Value added is defined as gross output minus intermediate inputs, where gross output is defined as sales plus other operating income. As discussed above, there are both advantages and disadvantages with using either value added or gross output in production analyses. We favor value added since it has the appealing property that nominal value added sums to GDP.

The specification is based on the standard augmented Cobb-Douglas production function. In addition to traditional capital it also includes R&D capital. The specification can be written:

$$\ln V_{i,t} = \beta_{ICT} \ln K_{ICT,i,t} + \beta_N \ln K_{N,i,t} + \beta_R \ln R_{i,t} + \beta_L \ln L_{i,t} + \delta_t D_t + \varepsilon_{i,t} \quad (11)$$

[6] The calculations of indexes for capital services and valued added were based on logged changes.

where $V_{i,t}$ is value added in industry i at time t, K_{ICT} is ICT capital, K_N is non-ICT capital, R is R&D capital, and L is labor input measured in hours. D_t is a set of year dummy variables included in order to control for economic shocks. These time dummies take out the average variation over time and let us identify the production function parameters through the cross-sectional variation. β is the elasticity of the subscripted variables and ε denotes serially uncorrelated random errors for each industry.

In addition to the specification in equation (12), it is also possible to divide ICT capital into hardware and software. The new specification then is:

$$\ln V_{i,t} = \beta_S \ln K_{S,i,t} + \beta_H \ln K_{H,i,t} + \beta_N \ln K_{N,i,t} + \beta_R \ln R_{i,t} + \beta_L \ln L_{i,t} + \delta_t D_t + \varepsilon_{i,t} \quad (12)$$

Where $K_{S,i,t}$ is software capital and $K_{H,i,t}$ is computer and communications hardware capital.

6. Results and discussion

6.1 The Basic Model

As argued by Stiroh (2002b), if one believes that the input choices are made before the productivity shocks, then pooled Ordinary Least Squares (OLS) estimators can be used to estimate equations (12) and (13). The results of these estimations are presented in *table 4*. For the regression based on ICT capital all coefficient are positive and highly significant. The estimated elasticity of ICT is 0.19, which indicates a considerable effect from ICT. The ICT capital coefficient remains high also after controlling for economic shocks by introducing annual time dummies. On average, if ICT capital increases by 10 percent, value added increases by 1.8 percent. The estimated coefficient for R&D is 0.10–0.11, although only significant at the 10 percent level. The estimated coefficient for non-ICT capital is approximately 0.30.

The ICT elasticity estimates are larger than the factor share of ICT in total income, which is on average approximately 0.10 for the investigated period. Based on the assumptions of competitive input markets (each input is paid its marginal product) and input exhaustion (all revenue is paid to factors) an input's factor share is equal to the elasticity (Stiroh 2002b).

However, our estimated elasticity is 80 percent higher than the share of ICT in total income, if we use the estimated elasticity coefficient of 0.18. This could reflect excess returns indicating that the marginal return of ICT outweighs marginal cost (Stiroh 2005). This raises the question why there is not even more investment in ICT. One possibility is that there is lack of information about the potential benefits for firms to invest in ICT, while another could be market regulations. A third possibility is that there is an omitted variable bias. Examples of omitted inputs that could be correlated with ICT are other intangibles such as vocational training and organizational capital. Complementary investments in new business processes, new skills and new organizational and industry structures are often necessary in order to get a high rate of return on ICT investments, both at the firm and aggregate level (Brynjolfsson and Hitt 2000).

When ICT is divided into hardware and software capital, the coefficients for all other independent variables remain highly significant and approximately unchanged. However, only software capital is significantly different from zero at an estimated elasticity of 0.22 and 0.23, respectively. Hardware is not significantly different from zero. Thus, software capital is found to have a larger effect on value added than hardware. One possibility could be that investments in software capital are more closely associated with organizational changes raising value added. Yet, one should keep in mind that both software and hardware are necessary to reap the benefits of ICT investments. Thus, another possible explanation could be that all industries invest in hardware, but only the ones that successfully invest in and implement the right software enjoy a positive effect from ICT. This is further supported by the fact that the results are unaffected if hardware is excluded.

In *table 4* we also present results when ICT producing industries are dropped from the sample.[7] The reason for dropping these industries is that value added and productivity growth has been particularly high in computer electronic and optical products (ISIC C26) (Edquist and Henrekson 2006). The results show that the coefficient for ICT capital remains

[7] The following industries are defined as ICT producing: Computer electronic and optical products (ISIC C26), telecommunications (ISIC J61) and Computer programming and related activities and information services (ISIC J62–J63). Based on the 2-digit industry level, this is the closest approximation to the OECD definition of ICT producing industries (see OECD 2009a).

unchanged at 0.19 and significant at the 1 percent level. Thus, the association between ICT capital and value added is robust to the exclusion of ICT producing industries. Moreover, the software component remains significant with a virtually unchanged point estimate. The R&D coefficient decreases and it becomes less significant.

6.2 Splitting the sample into manufacturing, services and different time periods

In *table 5* we present results when the sample is split into manufacturing and services.[8] For manufacturing, ICT and R&D capital are positive and highly significant. The elasticity is 0.48 for ICT capital and 0.27 for R&D. For hours worked and non-ICT capital, the elasticities are not significantly different from zero. When ICT is split into software and hardware capital, only hardware becomes positive and significant with a coefficient of 0.49. Thus, in manufacturing, hardware and R&D capital are found to be more strongly associated with value added than software capital.

For services the elasticity of ICT is significant at the 5 percent level, but the estimated effect of 0.18 is smaller than for manufacturing. Moreover, in contrast to manufacturing the coefficient of R&D is only 0.05 and not significant at the 10 percent level. Thus, R&D is less associated with value added in services compared to manufacturing. These findings are well in line with the fact that the ratio of intangible to tangible investments has increased in manufacturing relative to services (Edquist 2011b). Another noteworthy observation is that the coefficients for hours worked and non-ICT capital are positive and highly significant for services, in contrast to the findings for manufacturing where they are not significantly different from zero.

So far the findings have shown that ICT is positively associated with value added in both manufacturing and services. *Table 5* also shows the regression results based on services when ICT is divided into the software and hardware components. While the coefficient for software becomes positive and significant at the 10 percent level, the hardware coefficient is not significantly different from zero. Investment in hardware is thus more associated with value added in manufacturing, while software is more closely related to value added in

[8] Manufacturing is defined as industries C10–C33 and services as G45–T98 based on ISIC rev 4.

services. One possible explanation is that the production processes in manufacturing are more standardized and therefore more responsive to investments in hardware. Another explanation could be that hardware investments in manufacturing include software investments that are not separately registered as software.

Table 6 shows the results of the regressions split into three different time periods: 1993–2000, 2001–2007 and 2008–2012. According to Jorgenson et al. (2008) productivity growth in the US economy during the second half of the 1990s was driven both by productivity growth in the ICT producing industries and by the massive investments in ICT in the ICT using industries. However, after the 2000–2001 dot.com crash productivity growth has primarily taken place outside of the ICT producing industries. This motivates the choice of the first two periods. The third period examines the development after the global financial crisis starting in 2008.

According to *table 6*, the estimate of ICT capital remains robust to the disaggregation into three time periods; the estimated effect is significant and similar in size to the estimates in *table 4*. Thus, there is no evidence that the impact of ICT has decreased over time, and there is at least some evidence that the impact has increased. Similar to the regressions presented in *table 4*, only software has a positive and significant effect in all three periods. The coefficients for R&D are positive, although insignificant for two specifications. The significance level was generally higher for R&D in 2001–2007. *Table 6* also shows that the effect of non-ICT capital is highly significant for all periods. Moreover, hours worked is highly significant during the first two periods, but much less significant in 2008–2012.

6.3 Fixed effects and first differences

The regressions presented so far have ignored unobservable industry specific differences. In order to allow for these effects, it is possible to divide the error term into an industry specific component and a classical error term:

$$\ln V_{i,t} = \beta_{ICT} \ln K_{ICT,i,t} + \beta_N \ln K_{N,i,t} + \beta_R \ln R_{i,t} + \beta_L \ln L_{i,t} + \delta_t D_t + (\alpha_{i+} \varepsilon_{i,t}) \quad (13)$$

Where α_i is a set of unobserved industry specific effects and $\varepsilon_{i,t}$ is the error term. The fixed effects model is based on the idea that productivity shocks vary across industries even further and allow for an industry specific component that cannot be directly observed. A fixed effects model controls for or partials out the effects of these specific components.

The output elasticities can be estimated using different statistical techniques. We will use two methods. The first method is within-groups regression, where the mean values of the variables in the observations of a given industry are calculated and subtracted from the data of that industry. This removes the unobserved effect. The model explains the variation around the mean of the dependent variable in terms of the variations around the means of the explanatory variables for the group of observations for a given industry.

The second method takes the first difference of equation (8), which also removes the unobserved industry specific effects. The following equation is estimated:

$$\Delta \ln V_{i,t} = \beta_{Ict}\, \Delta \ln K_{ICT,i,t} + +\beta_O\, \Delta \ln K_{O,i,t} + \beta_R \Delta \ln R_{i,t} + \beta_L \Delta \ln L_{i,t} + \delta_t + v_{i,t} \quad (14)$$

where δ_t are year dummies, which capture common economic shocks, and $v_{i,t}$ is the differenced residual.

Table 7 shows the results for the within groups method. The elasticity of ICT capital remains positive and significant at the 5 percent level when time-specific effects are not included. However, when time-specific effects are included to control for common economic shocks, the coefficient of ICT capital becomes insignificant. The same results are found based on first differences. Stiroh (2005) obtains similar results when using fixed effects methods on US industry data for the period 1987–2000. He argues that the results could indicate an omitted variable that correlates with ICT, e.g., intangibles other than R&D. Moreover, Griliches and Mairesse (1995) conclude that estimating production functions based on the fixed effects methodology often results in unsatisfactory results such as low and insignificants coefficients for capital and unreasonably low elasticity estimates that do not add up to 1, i.e., they do not exhibit constant returns to scale.

The elasticities of hours worked and R&D remain significant at the 5 percent level when we control for industry and time-specific effects. The coefficients for R&D are much larger compared to the estimates based on pooled OLS. The coefficients vary between 0.20 and 0.34 depending on the method used. Moreover, the coefficients for R&D are significant at the 5 percent level with within-groups estimation, while they are significant at the 1 percent level based on first differences. Thus, R&D is more strongly associated with value added when industry-specific effects are taken into account.

Brynjolfsson and Hitt (2003) found that the returns of ICT increased when long term differences were introduced. These findings were based on firm level data and the suggested interpretation was that the observed contribution of computerization would be accompanied by relatively large and time consuming investments in complementary inputs, notably organizational capital. However, when long differences of 5 and 10 years are used, based on our data, the ICT coefficient remains insignificant. Long differences entail a loss of information; the number of observation decreases 21 and 47 percent, respectively. This reduces the precision of the estimations.

6.4 Discussion on simultaneity bias

Simultaneity bias constitutes another potential problem with the estimations presented here. It arises when one or more of the explanatory variables are determined jointly with the dependent variable. Thus, it could be argued that firms make decisions on the volume of inputs that are in part dependent on its performance. One way of dealing with this problem is to use instruments correlated with the inputs but uncorrelated with productivity shocks. Instruments that were used in previous studies are oil prices, defense spending shocks and monetary policy shocks (Basu et al. 2001; Stiroh 2005). However, we have not been able to find the corresponding data for these or any other reasonable instruments for Swedish industries.

Since there are no good instruments available, we will use internal instruments based on the Generalized Method of Moments (GMM). This means using two different dynamic panel

estimators. The first one is the Difference GMM (Arellano and Bond 1991). In this approach the equation is first estimated in first differences to correct for the fixed effect and then lagged values of the level of the dependent variable are used as instruments. The second approach is System GMM (Arellano and Bover 1995); Blundell and Bond 1998). It uses a stacked system of equations in first differences and levels. The System GMM estimator thus combines the standard set of equations in first differences with suitably lagged levels as instruments, with an additional set of equations in levels with suitably lagged first differences as instruments (Bond et al. 2001).

Figure 8 shows the results of the Difference GMM and System GMM estimations. Based on Difference GMM only hours worked remains positive and highly significant. However, ICT is not significant and the same results are found for hardware and software. However, based on System GMM, ICT is highly significant with a coefficient of 0.11. However, hours worked and R&D are not significant, but the coefficient of other capital is significantly negative at the 10 percent level. According to Draca et al. (2006) industry data are too coarse for some of the more sophisticated econometric approaches such as GMM. Thus, results based on these methods should be interpreted with caution.

7. Conclusions

From the mid-1990s until recently both productivity growth and GDP growth was rapid in Sweden relative to most other countries at comparable levels of income. Particularly the business sector experienced high rates of growth. Explaining with precision to what extent different factors have contributed to this development is no easy task.

ICT and R&D have been identified as important drivers of economic growth. In the last 20 years Sweden has experienced a revolution in ICT. For example, in the 1990s the number of mobile phone subscriptions and the use of Internet increased rapidly, and today the Internet is to a large extent mobile. Manufacturing of computer, electronic and optical products (ISIC C26) is also the industry that has invested the most in R&D in recent years.

Based on econometric estimations of neoclassical production functions we show that ICT and R&D capital is associated with greater value added for most specifications. Based on pooled OLS regressions the highly significant estimated coefficient is 0.19 for ICT capital. The results are robust to the inclusion of time dummies to adjust for economic shocks and to the exclusion of ICT producing industries. When ICT capital is divided into hardware and software, only software is significantly associated with value added. One possible explanation could be that all industries invest in hardware, but only the ones that successfully invest in and implement software enjoy positive effects from ICT. The estimated elasticity for R&D capital in the pooled regressions is 0.11, but it is only significant at the 10 percent level. Moreover, when the ICT producing industries are excluded the estimated coefficient for R&D becomes smaller and the level of significance drops.

When the sample is split into manufacturing and services the ICT coefficient remains significant at the 1 percent level for manufacturing and at the 5 percent level for services. However, in manufacturing only hardware is strongly associated with value added, while the opposite is true for services. For some reason the production processes within manufacturing and services are affected differently by hardware and software capital. Moreover, the elasticity of R&D capital is 0.27 and highly significant for manufacturing, while it is insignificant for services. The fact that R&D capital is only positively associated with value added in manufacturing suggests that innovation processes differ between manufacturing and services.

The estimated ICT coefficients remains large and significantly associated with value added also when the sample is spilt into three time periods: 1993–2000, 2001–2007 and 2008–2012. There is no evidence of a falling impact of ICT over time; if anything, the evidence suggests that the effect has increased.

When fixed effects estimation is used the ICT coefficient remains significant at the 5 percent level. However, when both fixed effects and time dummies are included in the regression the ICT coefficient becomes insignificant. One reason could be that there are omitted variables

that correlate with ICT. Similar results are found for the US. Furthermore, R&D capital is strongly associated with value added when we control for industry specific effects.

In summary, our results show that both ICT and R&D capital are positively associated with value added in the Swedish non-farm business sector. The estimated coefficients are large and significant for most specifications. When controlling for economic shocks the results show that on average, if ICT capital increases by 10 percent, value added increases by 1.8 percent. Our results also suggest that countries with an industry structure similar to that of Sweden would benefit from developing or strengthening institutions that encourage investments in ICT and R&D.

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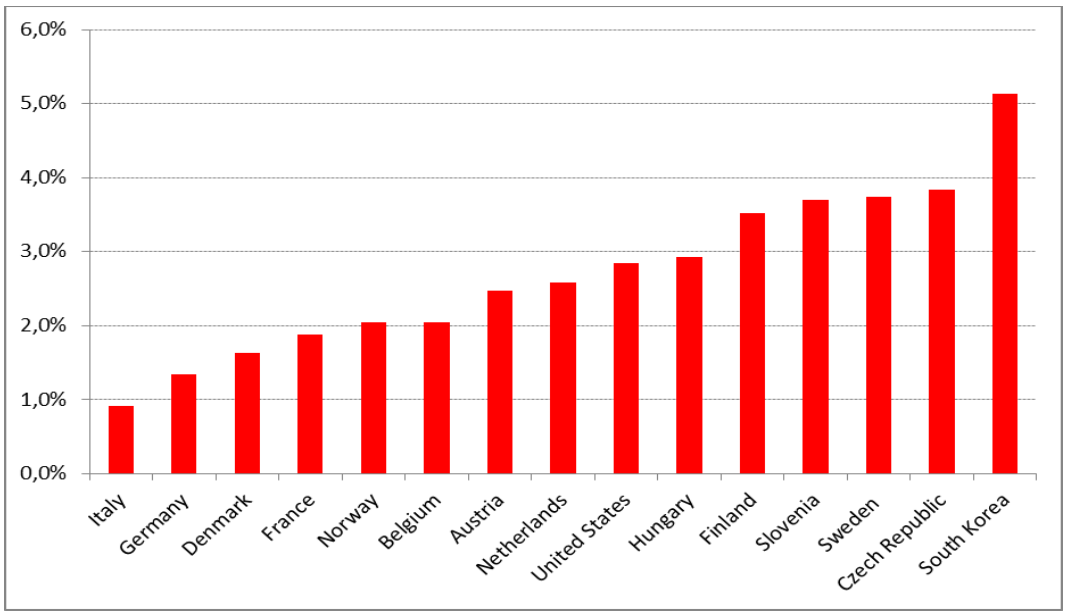
8. Table and figures

8.1 Figures

Figure 1 Average annual value added growth in the non-farm business sector in fifteen OECD countries 1995–2010



Note: Countries have been included based on data availability. Data is based on industry classifications according to ISIC rev. 4.

Source: OECD (2015c).

Table 1 Types of capital included when calculating capital services

Type of capital
Dwellings
Other buildings
Transportation equipment
ICT hardware
Other machinery and equipment and weapon systems
Research and development
Software

Source: Statistics Sweden (2015).

Table 2 Depreciation rates used for each type of capital and industry

ISIC Rev.4	Dwellings	Other buildings	Transport equip	ICT hardware	Other machine	R&D	ICT software
B05–09	0.011	0.024	0.170	0.161	0.129	0.165	0.315
C10–C12	0.011	0.033	0.168	0.161	0.109	0.165	0.315
C13–C15	0.011	0.033	0.184	0.161	0.109	0.165	0.315
C16	0.011	0.032	0.183	0.161	0.109	0.165	0.315
C17	0.011	0.033	0.173	0.161	0.106	0.165	0.315
C18	0.011	0.033	0.173	0.161	0.106	0.165	0.315
C19	0.011	0.032	0.154	0.161	0.110	0.165	0.315
C20–C21	0.011	0.033	0.181	0.161	0.104	0.165	0.315
C22	0.011	0.033	0.202	0.161	0.113	0.165	0.315
C23	0.011	0.033	0.191	0.161	0.112	0.165	0.315
C24	0.011	0.033	0.169	0.161	0.106	0.165	0.315
C25	0.011	0.033	0.169	0.161	0.106	0.165	0.315
C26	0.011	0.033	0.166	0.161	0.108	0.165	0.315
C27	0.011	0.033	0,166	0.161	0.108	0.165	0.315
C28	0.011	0.033	0.170	0.161	0.107	0.165	0.315
C29	0.011	0.033	0.167	0.161	0.109	0.165	0.315
C30	0.011	0.033	0.167	0.161	0.109	0.165	0.315
C31–C32	0.011	0.033	0.193	0.161	0.113	0.165	0.315
C33	0.011	0.033	0.193	0.161	0.113	0.165	0.315
DD35	0.011	0.023	0.191	0.161	0.094	0.165	0.315
E36–E37	0.011	0.023	0.191	0.161	0.094	0.165	0.315
E38–E39	0.011	0.023	0.191	0.161	0.094	0.165	0.315
F41–F43	0.011	0.034	0.195	0.161	0.139	0.165	0.315
G45	0.011	0.031	0.229	0.161	0.121	0.165	0.315
G46	0.011	0.031	0.204	0.161	0.143	0.165	0.315
G47	0.011	0.027	0.215	0.161	0.137	0.165	0.315
H49	0.011	0.028	0.092	0.161	0.118	0.165	0.315
H50	0.011	0.028	0.092	0.161	0.118	0.165	0.315
H51	0.011	0.028	0.092	0.161	0.118	0.165	0.315
H52–H53	0.011	0.027	0.201	0.161	0.096	0.165	0.315
H55–H56	0.011	0.028	0.203	0.161	0.140	0.165	0.315
J58	0.011	0.033	0.173	0.161	0.106	0.165	0.315
J59–J60	0.011	0.033	0.173	0.161	0.106	0.165	0.315
J61	0.011	0.027	0.201	0.161	0.096	0.165	0.315
J62–J63	0.011	0.044	0.155	0.161	0.144	0.165	0.315
K64	0.011	0.044	0.187	0.161	0.149	0.165	0.315
K65	0.011	0.044	0.187	0.161	0.149	0.165	0.315
K66	0.011	0.044	0.187	0.161	0.149	0.165	0.315
L68A	0.011	0.027	0.227	0.161	0.147	0.165	0.315
L68B	0.011	0.027	0.227	0.161	0.147	0.165	0.315
M69–M70	0.011	0.044	0.155	0.161	0.144	0.165	0.315
M71–M72	0.011	0.044	0.155	0.161	0.144	0.165	0.315
M73–M75	0.011	0.044	0.155	0.161	0.144	0.165	0.315
N77	0.011	0.044	0.155	0.161	0.144	0.165	0.315
N78–N82	0.011	0.044	0.155	0.161	0.144	0.165	0.315
P85	0.011	0.025	0.173	0.161	0.138	0.165	0.315
P86	0.011	0.027	0.225	0.161	0.149	0.165	0.315
Q87–Q88	0.011	0.027	0.225	0.161	0.149	0.165	0.315
R90–R93	0.011	0.051	0.223	0.161	0.136	0.165	0.315
S94–T98	0.011	0.051	0.223	0.161	0.136	0.165	0.315

Source: EU KLEMS (2011) and Statistics Sweden (2015).

Table 3 List of industries included in the regression analysis

Industry	ISIC Rev.4
Mineral extract	B05–09
Food	C10–C12
Textile, clothing and leather products	C13–C15
Wood and wood products	C16
Paper and paper products	C17
Printing and reproduction of recorded media	C18
Coke and refined petroleum products	C19
Chemical, chemical products and pharmaceutical products	C20–C21
Rubber and plastic products	C22
Non-metallic mineral products	C23
Basic metals	C24
Fabricated metal products except machinery and equipment	C25
Computer, electronic and optical products	C26
Electrical equipment	C27
Machinery and equipment	C28
Motor vehicles, trailers and semi-trailers	C29
Other transportation equipment	C30
Furniture and other manufacturing	C31–C32
Repair and installation of machinery and equipment	C33
Electricity, gas and steam	D35
Water collection and sewerage	E36–E37
Waste collection, materials recovery and remediation	E38–E39
Construction	F41–F43
Wholesale and retail trade of motor vehicles and motorcycles	G45
Wholesale trade except of motor vehicles and motorcycles	G46
Retail trade except of motor vehicles and motorcycles	G47
Land transport and transport via pipelines	H49
Water transport	H50
Air transport	H51
Warehousing and postal and courier activities	H52–H53
Hotels and restaurants	H55–H56
Publishing activities	J58
Motion picture, programming and broadcasting	J59–J60
Telecommunications	J61
Computer programming and related activities and information services	J62–J63
Financial service activities	K64
Insurance, reinsurance and pension funding	K65
Activities auxiliary to financial service and insurance activities	K66
Real estate activities with own or leased property	L68A
Other real estate activities	L68B
Legal and accounting activities and management consulting	M69–M70
Architectural and engineering activities and scientific research and development	M71–M72
Advertising, market research and veterinary activities	M73–M75
Rental and leasing activities	N77
Administrative and support service activities	N78–N82
Education	P85
Health activities	P86
Human health activities	Q87–Q88
Arts, entertainment and recreation	R90–R93
Other service activities and activities of households as employers	S94–T98

Source: ISIC (2008).

Table 4 Production function regressions for the Swedish non-farm business sector

	Dependent variable: Value added					
	Basic regression OLS		Time adjustment OLS		Drop ICT-producing OLS	
Hours worked (**ln***L*)	0.39***	0.32***	0.39***	0.32***	0.42***	0.35***
	(0.115)	(0.117)	(0.115)	(0.118)	(0.117)	(0.123)
ICT capital (**ln***K_{ICT}*)	0.19***		0.18***		0.19***	
	(0.056)		(0.059)		(0.064)	
Software capital (**ln***K_S*)		0.22**		0.23***		0.24**
		(0.083)		(0.084)		(0.095)
Hardware capital (**ln***K_H*)		0.02		0.004		0.01
		(0.048)		(0.049)		(0.048)
Non-ICT capital (**ln***K_N*)	0.30***	0.32***	0.29***	0.32***	0.30***	0.32***
	(0.056)	(0.039)	(0.056)	(0.039)	(0.054)	(0.039)
R&D capital (**ln***R*)	0.11*	0.10*	0.11*	0.10*	0.05*	0.04
	(0.055)	(0.055)	(0.055)	(0.056)	(0.029)	(0.027)
Time dummies	No	No	Yes	Yes	Yes	Yes
Adjusted $\boldsymbol{R}^2$	0.72	0.74	0.72	0.74	0.77	0.80
Number of observations	940	940	940	940	880	880

Note: The estimates are based on OLS regression for 47 industries in the period 1993–2012. Cluster robust standard errors are presented in parenthesis. ***, **, * indicate statistical significance at the 1%, 5% and 10% levels, respectively. Hardware capital includes computer and telecommunications equipment. The following industries are defined as ICT producing: Computer electronic and optical products (ISIC C26), telecommunications (ISIC J61) and Computer programming and related activities and information services (ISIC J62–J63).

Table 5 Production function regressions for the Swedish non-farm business sector

	Dependent variable: Value added			
	Manufacturing OLS		Services OLS	
Hours worked (**ln***L*)	–0.03	–0.03	0.43***	0.38***
	(0.170)	(0.179)	(0.053)	(0.076)
ICT capital (**ln***K_{ICT}*)	0.48***		0.18**	
	(0.126)		(0.069)	
Software capital (**ln***K_S*)		–0.10		0.26*
		(0.247)		(0.128)
Hardware capital (**ln***K_H*)		0.49**		–0.02
		(0.196)		(0.055)
Non-ICT capital (**ln***K_N*)	–0.09	–0.09	0.31***	0.31***
	(0.308)	(0.316)	(0.067)	(0.052)
R&D capital (**ln***R*)	0.27***	0.30**	0.05	0.004
	(0.090)	(0.122)	(0.036)	(0.044)
Time dummies	Yes	Yes	Yes	Yes
Adjusted $\boldsymbol{R}^2$	0.76	0.76	0.80	0.83
Number of observations	360	360	480	480

Note: The estimates are based on OLS regression for the period 1993–2012. Manufacturing is defined as C10–C33 and services as G45–T98 based on ISIC rev 4. Cluster robust standard errors are presented in parenthesis. ***, **, * indicate statistical significance at the 1%, 5% and 10% levels, respectively. Hardware capital includes computer and telecommunications equipment.

Table 6 Production function regressions for the Swedish non-farm business sector

	Dependent variable: Value added					
	1993–2000 OLS		2001–2007 OLS		2008–2012 OLS	
Hours worked (**ln***L*)	0.48***	0.42***	0.37***	0.30**	0.30*	0.23
	(0.083)	(0.086)	(0.118)	(0.122)	(0.169)	(0.170)
ICT capital (**ln***K_{ICT}*)	0.16***		0.18***		0.21**	
	(0.053)		(0.060)		(0.083)	
Software capital (**ln***K_S*)		0.20**		0.22**		0.28**
		(0.079)		(0.090)		(0.110)
Hardware capital (**ln***K_H*)		–0.01		0.01		0.002
		(0.053)		(0.056)		(0.073)
Non-ICT capital (**ln***K_N*)	0.29***	0.30***	0.31***	0.34***	0.28***	0.33***
	(0.054)	(0.043)	(0.060)	(0.038)	(0.072)	(0.049)
R&D capital (**ln***R*)	0.07*	0.06	0.12**	0.11*	0.14*	0.12
	(0.038)	(0.038)	(0.060)	(0.060)	(0.076)	(0.076)
Time dummies	Yes	Yes	Yes	Yes	Yes	Yes
Adjusted $\boldsymbol{R}^2$	0.82	0.84	0.72	0.74	0.58	0.61
Number of observations	376	376	329	329	235	235

Note: The estimates are based on OLS regression for the periods 1993–2000, 2001–2007 and 2008–2012. Cluster robust standard errors are presented in parenthesis. OLS is ordinary least squares. ***, **, * indicate statistical significance at the 1%, 5% and 10% levels, respectively. Hardware capital includes computer and telecommunications equipment.

Table 7 Production function regressions for the Swedish non-farm business sector

	Dependent variable: Value added					
	Fixed effects Excl. time dummies		Fixed effects Incl. time dummies		First differences	
Hours worked (**ln***L*)	0.33*	0.33**	0.40**	0.39**	0.62***	0.63***
	(0.168)	(0.165)	(0.164)	(0.165)	(0.098)	(0.098)
ICT capital (**ln**K_{ICT})	0.13**		–0.02		0.01	
	(0.050)		(0.087)		(0.060)	
Software capital (**ln**K_S)		0.13*		–0.004		–0.03
		(0.071)		(0.076)		(0.019)
Hardware capital (**ln**K_H)		0.06*		–0.004		–0.002
		(0.030)		(0.045)		(0.035)
Non-ICT capital (**ln**K_N)	0.27**	0.22*	0.12	0.12	0.01	0.02
	(0.113)	(0.118)	(0.120)	(0.120)	(0.083)	(0.085)
R&D capital (**ln***R*)	0.33**	0.34**	0.29**	0.29**	0.21***	0.20***
	(0.145)	(0.141)	(0.129)	(0.129)	(0.040)	(0.040)
Time dummies	No	No	Yes	Yes	Yes	Yes
Adjusted $\boldsymbol{R}^2$	0.50	0.51	0.53	0.53	0.23	0.23
Number of observations	940	940	940	940	893	893

Note: The estimates are based on fixed effects regressions for the period 1993–2012. Robust standard errors are presented in parenthesis. ***, **, * indicate statistical significance at the 1%, 5% and 10% level, respectively. Hardware capital includes computer and telecommunications equipment.

Table 8 Production function regressions with internal instruments for the Swedish non-farm business sector

	Dependent variable: Value added			
	Difference GMM		System GMM	
Hours worked (**ln***L*)	0.20***	0.24***	0.004	–0.003
	(0.065)	(0.055)	(0.056)	(0.055)
ICT capital (**ln***K_{ICT}*)	0.05		0.12***	
	(0.035)		(0.038)	
Software capital (**ln***K_S*)		–0.09		0.06*
		(0.063)		(0.030)
Hardware capital (**ln***K_H*)		0.01		0.05**
		(0.020)		(0.023)
Non-ICT capital (**ln***K_N*)	0.03	0.01	–0.09*	–0.08*
	(0.066)	(0.066)	(0.046)	(0.045)
R&D capital (**ln***R*)	0.04	0.03	0.04	0.04
	(0.073)	(0.081)	(0.031)	(0.029)
Time dummies	Yes	Yes	Yes	Yes
Number of observations	846	846	893	893

Note: The estimates are based on dynamic panel-data models for 47 industries in the period 1993–2012. Robust standard errors are presented in parenthesis. ***, **, * indicate statistical significance at the 1%, 5% and 10% level, respectively. Hardware capital includes computer and telecommunications equipment.