# Swedish Lessons: How Important are ICT and R&D to Economic Growth?

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# Swedish Lessons: How Important are ICT and R&D to Economic Growth?[*]

By

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## Abstract

We investigate to what extent ICT and R&D capital is associated with value added growth in the Swedish business sector. By estimating output elasticities based 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. 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. Finally, we use the growth accounting framework to compare the contribution from ICT and R&D to value added growth when output elasticities are based on either income shares or weighted least squares (WLS) estimates. The contribution of ICT to value added growth increases from 0.9 to 1.5 percentage points when WLS estimates are used instead of income shares.

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

*Keywords*: ICT; R&D; Industrial change; Panel data.

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## 1. Introduction

For a long time investment in information and communications technology (ICT) and R&D has been emphasized as important for technical change and economic growth (e.g., Schumpeter 1942; Nelson 1959; Griliches 1991; Brynjolfsson and McAfee 2014). Since the mid-1990s both value added and productivity have grown rapidly in the Swedish business sector.[1] The average annual value added growth was 3.4 percent in 1993–2012. This is a strong development compared to many other OECD countries (see *figure 1*).

Evidence from the US economy suggests that the 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 in total investment in the 2000s (OECD 2015b). Research also shows that investment in intangible assets through R&D is important for growth in value added and productivity (Corrado et al. 2009; Marrano et al. 2009). Sweden has also had higher R&D investment as a share of GDP compared to most other countries (OECD 2015a).

Given the high rates of aggregate ICT and R&D investment in Sweden it is of particular interest to explore whether such investments are associated with higher value added. Were this to be the case, it would suggest that ICT and R&D investments are economically justified, and 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 the period 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. Finally, we use the growth accounting framework to investigate the total contribution from ICT and R&D to economic growth in the Swedish business sector when output elasticities are based on either income shares or weighted least squares (WLS) estimates. More specifically, we investigate the following questions:

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[1] When the business sector is referred to in this paper it is defined as the non-farm business sector and thus excludes agriculture, forestry and fishing.

- 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?
- Based on the growth accounting framework, what is the contribution from ICT and R&D when output elasticities are based on income shares or WLS estimates, respectively?

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 1.7 percent. The corresponding elasticity for R&D capital 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.

Finally, we use elasticities based on either WLS estimates or income shares in a growth accounting framework to measure the contribution of ICT and R&D. We find that the contribution of ICT to value added growth increases from 0.9 to 1.5 percentage points when WLS estimates of elasticities are used instead of income shares. The corresponding figure for R&D is an increased contribution from 0.36 to 0.43 percentage points.

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, section 7 provides a sensitivity analysis and Section 8 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 due to the need for complementary organizational investments that take time to implement.

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 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 and estimating each input's contribution to economic growth based on the growth accounting framework.

In summary, the literature suggests that ICT capital has been an important source of economic and productivity growth at the aggregate, industry and firm-levels. Moreover, the same is true for R&D, which in addition to being a direct source of growth 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]

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

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[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.

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

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

By taking natural logarithms of equation (2):

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

where $\beta$ 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:[5]

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[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.
[5] In order to use this method a base-year level of the capital stocks is required. This is estimated by Statistics Sweden (2015) for the year 1993.

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

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 ($i$):

$$irr_{i,t} = \frac{p_t^K K_t + \Sigma_s(p_{s,i,t}^I - p_{s,i,t-1}^I)K_{s,i,t} - \Sigma_s p_{s,i,t}^I \delta_{s,i,t} K_{s,i,t}}{\Sigma_s p_{s,i,t-1}^I K_{s,i,t}} \tag{5}$$

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. $p_{s,i,t}^I$ 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 ($p_{s,i,t}^K$) 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:

$$p_{s,i,t}^K = p_{s,i,t-1}^I irr_{i,t} + \delta_{s,i,t} p_{s.i,t}^I - (p_{s,i,t}^I - p_{s,i,t-1}^I) \tag{6}$$

where $irr_{i,t}$ is the internal rate of return, $\delta_{s,i,t}$ is the depreciation rate and $p_{s,i,t}^I$ 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:

$$c_{s,i,t} = p^K_{s,i,t} K_{s,i,t} \tag{7}$$

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

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

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:

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

$$v_{s,i,t} = \frac{c_{s,i,t}}{\sum_s c_{s,i,t}} \tag{10}$$

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

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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).[6]

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.

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

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[6] 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).

capital formation (GFCF), which implies a depreciation rate of 16.1 percent for hardware and 31.5 percent for software 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.[7]

## 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:

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

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-

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

sectional variation. $\beta$ is the elasticity of the subscripted variables and $\varepsilon$ denotes serially uncorrelated random errors for each industry.

In addition to the specification in equation (11), 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 (11) and (12). 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.

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 based on weighted least squares (WLS), where value added weights in current prices are used. Stiroh (2005) argues that WLS is more appropriate because the variance of residuals is inversely related to industry size. Thus, estimates based on WLS might provide a better historical view of the Swedish economy as industries vary in size. However, the estimates are very similar to the OLS estimates. The coefficient for ICT capital becomes 0.17 instead of 0.18 and the coefficient for R&D capital remains unchanged at 0.11.

## 6.2 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 $\alpha_i$ 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 $\delta_t$ are year dummies, which capture common economic shocks, and $v_{i,t}$ is the differenced residual.

*Table 5* 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.

## 6.3 Discussion of 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).

*Table 6* 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. Moreover, the Sargan test shows that we cannot reject the null hypothesis of valid instruments. Based on System GMM, ICT is highly significant with a coefficient of 0.12 and the Sargan test again shows that the null hypothesis of valid instruments cannot be rejected. However, hours worked and R&D are not significant, but the coefficient of other capital is significantly negative at the 5 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.

## 6.4 The contribution of ICT and R&D to aggregate growth

Our results show that ICT and R&D capital is associated with greater value added for most specifications based on industry-level data. However, it is not clear to what extent ICT and R&D capital contribute to aggregate value added growth in the Swedish business sector. One way to estimate the contribution from ICT and R&D is to use the growth accounting framework based on elasticities either from income shares or from econometric estimates. Growth accounting assesses the contribution of inputs to economic growth assuming constant returns to scale and that each factor receives compensation equal to its marginal productivity (Niebel et al. 2013). The relation can then be written:

$$\Delta \ln V = s_{ICT} \, \Delta \ln K_{ICT} + s_N \Delta \ln K_N + s_R \Delta \ln R + s_L \Delta \ln L + \Delta \ln TFP \qquad (15)$$

where $V$ is aggregate value added, $K_{ICT}$ is ICT capital, $K_N$ is non-ICT capital, $R$ is R&D capital, $L$ is labor input measured in hours, and $TFP$ is total factor productivity measured as a residual.

Based on the assumptions of competitive markets and constant returns to scale it is possible to let the elasticities ($s_{ICT}$, $s_N$, $s_R$, $s_L$) be equal to each factor's income share. When econometric estimation is used instead these assumptions are not necessary. Thus, unlike growth accounting, estimates based on econometric estimation show the contributions to growth from individual inputs as parameters rather than calculating them from income statistics. Moreover, the advantage of using industry data instead of firm level data is that the estimates are more likely to represent the average of the business sector as a whole. Firm level data are usually based on limited samples and are therefore likely to be less representative of the total business sector.

*Figure 2* shows the contribution from each input based on the growth accounting methodology in 1993–2012. Output elasticities are based either on income shares or weighted least squares estimates (WLS).[8] A motivation for using WLS is that it provides a better representation of the aggregate business sector because industries vary in size and the classifications can be considered somewhat arbitrary (Strioh 2005).

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[8] The output elasticites based on WLS estimations include time dummy variables.

When output elasticities are based on WLS estimation instead of income shares, the contribution of ICT to value added growth increases from 0.9 to 1.5 percentage points. The reason for this large difference is that 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 70 percent higher than the share of ICT in total income, if we use the estimated elasticity coefficient of 0.17. 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).

*Figure 2* also shows that the contribution from R&D increases marginally from 0.36 to 0.43 percentage points when output elasticities are based on WLS estimation. The relative contribution by hours worked and non-ICT capital decreases slightly when output shares are based on WLS estimation rather than on income shares.

In summary, ICT and R&D together account for 1.2 percentage points of value added growth in the Swedish business sector in 1993–2012 based on income shares, while the corresponding figure is 1.9 percentage points based on WLS estimation of output elasticities. Sector. Depending on the method used to estimate output elasticities, this implies that ICT and R&D account for either 36 or 58 percent of total value added growth in the Swedish business sector. Thus, ICT and R&D investments have been prime drivers of growth in the business sector since the mid-1990s.

## 7. Sensitivity Analysis

*Table 7* presents a sensitivity analysis of the OLS and WLS estimates. We begin by dropping ICT producing industries. Value added and productivity growth has been particularly high in computer electronic and optical products (ISIC C26) (Edquist and Henrekson 2006), which could potentially bias the results. However, the ICT coefficient is unaffected when ICT producing industries are dropped, while the R&D coefficient decreases and becomes less significant.

We then check robustness by splitting the regressions 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 ICT investments 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 (Jorgenson et al. 2008). This motivates the choice of the first two periods. The third period examines the development after the global financial crisis starting in 2008. The estimate of ICT capital remains robust to the disaggregation into the three time periods. The coefficients for R&D are positive and generally higher in the last two periods. The significance level was generally higher for R&D in 2001–2007.

Finally, *table 7* also shows the coefficients for ICT and R&D when the sample is divided into manufacturing and services. The results show that the coefficients for ICT and R&D are higher in manufacturing compared to services. However, even if the ICT coefficient in clearly larger in manufacturing it is still significant at the 5 percent level for services. Moreover, the R&D coefficient is highly significant in manufacturing, but insignificant for services. Thus, R&D is less associated with value added in services compared to manufacturing.

In section 6.4, the elasticities estimated by weighted least squares (WLS) were used in a growth accounting framework to estimate the impact on total growth by ICT and R&D. It was argued that the estimates based on WLS would be most representative for the total business sector because industries vary in size and the classifications can be considered somewhat arbitrary. *Figure 3* shows the total contribution from ICT and R&D based on

elasticities estimated in three different ways (based on specifications where both the estimated coefficients of ICT and R&D are significant at the 10 percent level or higher).

The estimated contribution from ICT becomes greater when econometric estimates are used instead of income shares. Moreover, the estimated contribution from R&D becomes considerably greater when elasticities are based on fixed effects estimates excluding time dummies. Even though there is some variation depending on method used to estimate output elasticities, it is safe to conclude that both ICT and R&D investments have been important drivers of value added growth in the Swedish business sector in recent decades.

## 8. Conclusions

From the mid-1990s until recently both productivity growth and GDP growth was rapid in Sweden. Particularly the business sector experienced high rates of growth. The annual value added growth was 3.4 percent, which is also high compared to many other OECD-countries. 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.

We estimate output elasticities of ICT, R&D and other inputs based on econometric estimation of the neoclassical production function. We show that ICT and R&D capital is associated with greater value added for most specifications. Controlling for both economic shocks and the fact that the variance is often larger for small industries, the coefficient for ICT capital is 0.17. Thus, an increase of ICT capital by 10 percent is associated with a 1.7 percent increase in value added.

When ICT capital is divided into hardware and software, only software is significantly associated with value added. To our knowledge this distinction has not been made in any previous study at the industry level. 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 based on weighted least squares in the pooled regressions is 0.11, but it is only significant at the 10 percent level.

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.

Finally, we use the growth accounting framework to compare the contribution of inputs when output elasticities are based on income shares and WLS estimations, respectively. When output elasticities are based on WLS instead of income shares, the contribution of ICT to value added growth increases from 0.9 to 1.5 percentage points. Possible explanations to the differences are excess returns, lack of information, market regulations and omitted variable bias.

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. Moreover, ICT and R&D accounted for 36 or 58 percent of value added growth depending on whether output elasticities were based on income shares or WLS estimations. Thus, it can be concluded that the growth contribution of ICT and R&D investments has been substantial. 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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## Figures and tables

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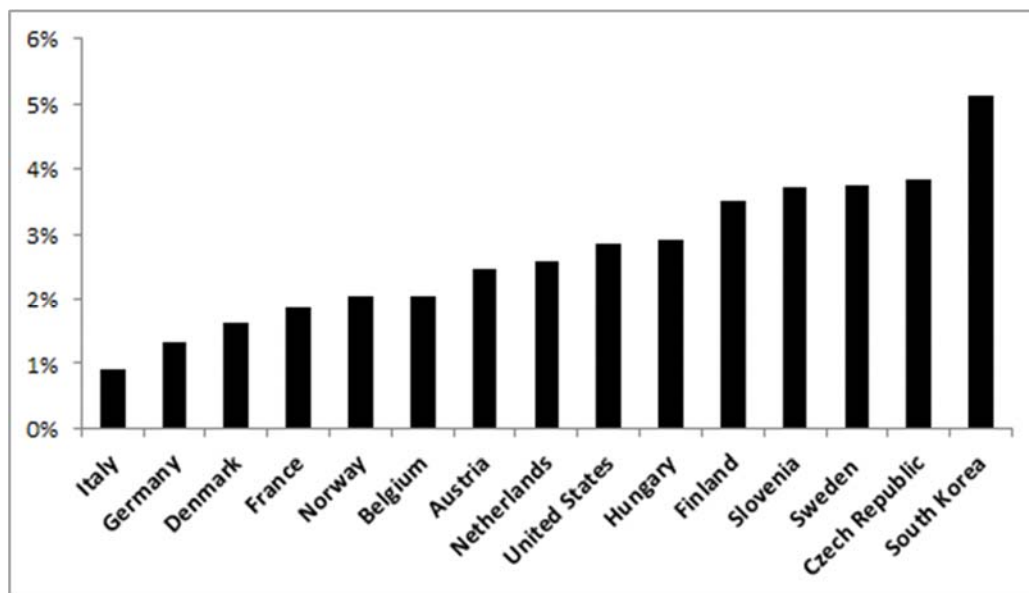


*Note*: Countries have been included based on data availability. Data is based on industry classifications according to ISIC rev. 4 and real estate activities are excluded.

*Source*: OECD (2015c).

**Figure 2   Growth accounting for the Swedish non-farm business sector in 1993–2012, based on income shares and WLS estimates of output elasticities**
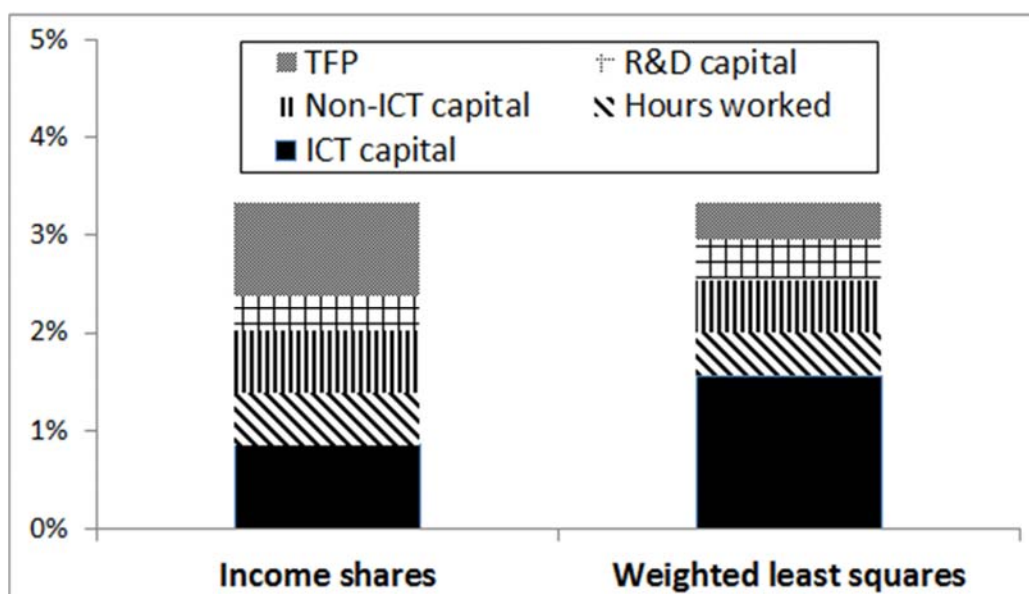


*Source*: Statistics Sweden (2015) and own calculations.

**Figure 3    Contribution from ICT and R&D based on the growth accounting framework with different estimates of output elasticities**
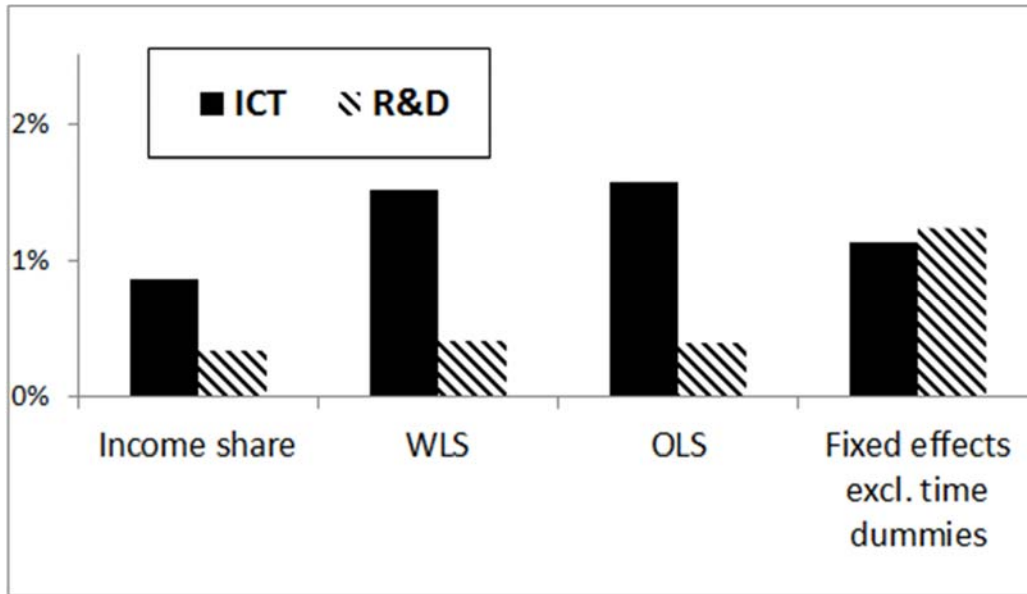


*Source*: Statistics Sweden (2015) and own calculations.

**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 | | Time adjustment WLS | |
| Hours worked ($\ln L$) | 0.39*** | 0.32*** | 0.39*** | 0.32*** | 0.40*** | 0.34*** |
| | (0.115) | (0.117) | (0.115) | (0.118) | (0.107) | (0.112) |
| ICT capital ($\ln K_{ICT}$) | 0.19*** | | 0.18*** | | 0.17*** | |
| | (0.056) | | (0.059) | | (0.061) | |
| Software capital ($\ln K_S$) | | 0.22** | | 0.23*** | | 0.23** |
| | | (0.083) | | (0.084) | | (0.088) |
| Hardware capital ($\ln K_H$) | | 0.02 | | 0.004 | | −0.007 |
| | | (0.048) | | (0.049) | | (0.049) |
| Non-ICT capital ($\ln K_N$) | 0.30*** | 0.32*** | 0.29*** | 0.32*** | 0.29*** | 0.32*** |
| | (0.056) | (0.039) | (0.056) | (0.039) | (0.061) | (0.040) |
| R&D capital ($\ln R$) | 0.11* | 0.10* | 0.11* | 0.10* | 0.11* | 0.10 |
| | (0.055) | (0.055) | (0.055) | (0.056) | (0.059) | (0.059) |
| Time dummies | No | No | Yes | Yes | Yes | Yes |
| Adjusted $R^2$ | 0.72 | 0.74 | 0.72 | 0.74 | 0.71 | 0.74 |
| Number of observations | 940 | 940 | 940 | 940 | 940 | 940 |

*Note*: The estimates are based on OLS and WLS regressions 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. WLS estimates are based on weights of the logarithm of value added in current prices.

**Table 5    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 | |
| | (0.049) | | (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 | | −0.003 |
| | | (0.030) | | (0.045) | | (0.035) |
| Non-ICT capital ($\ln K_N$) | 0.27** | 0.22* | 0.12 | 0.12 | 0.01 | 0.01 |
| | (0.113) | (0.118) | (0.120) | (0.120) | (0.082) | (0.084) |
| 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 $R^2$ | 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 6    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 |
| Sargan statistic | 26.5 | 23.4 | 29.5 | 29.6 |
| Sargan p-value | 1.00 | 1.00 | 1.00 | 1.00 |
| 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. The Sargan statistic is based on the two-step version of the GMM estimator, while coefficients are based on the one-step version. According to Arellano and Bond (1991) the one-step Sargan test is sensitive to heteroskedasticity and may overreject the null hypothesis.


**Table 7    Sensitivity analysis**

| | Dependent variable: Value added | | | |
|---|---|---|---|---|
| | ICT-coefficient | | R&D coefficient | |
| | OLS | WLS | OLS | WLS |
| Baseline regression | 0.18*** | 0.17*** | 0.11* | 0.11* |
| Drop ICT industries | 0.19*** | 0.18*** | 0.05* | 0.05 |
| 1993–2000 | 0.16*** | 0.16*** | 0.07* | 0.07* |
| 2001–2007 | 0.18*** | 0.17*** | 0.12** | 0.13** |
| 2008–2012 | 0.21** | 0.20** | 0.14* | 0.14* |
| Manufacturing | 0.48*** | 0.50*** | 0.27*** | 0.28*** |
| Services | 0.18** | 0.19** | 0.05 | 0.04 |

*Note*: The estimates are based on OLS and WLS regressions 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. Manufacturing is defined as C10–C33 and services as G45–T98 based on ISIC rev 4. 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). All estimations include time dummy variables.