The Role of High-Tech Capital Formation for Swedish Productivity Growth*

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Abstract

While using new data and standard growth-accounting techniques, this paper takes a closer look at the Swedish productivity revival in the second half of the 1990s. In particular, I find large total factor productivity growth in high-tech producing sectors and capital deepening associated with high-tech equipment elsewhere. In addition, for high-tech producers, high-tech capital deepening has as a rule contributed negatively to labor productivity growth – a result above all driven by large increases in hours worked in this sector. I also find that in the business sector, the contribution from high-tech capital deepening to labor productivity growth increased from about 1 percent 1994 to 9 percent 1999.

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1 Introduction

Throughout the 1990s the Swedish economy experienced a fairly strong resurgence in average labor productivity (ALP) growth (c.f. figures 1 and 2). After growing only about 1.2 percent per year from 1981 through 1990, labor productivity growth for the economy as a whole jumped to close to 2 percent per year over the period 1991-2000. Annual labor productivity growth for the total business sector averaged slightly more than 2.5 percent over the period 1991-2000 – about a 50 percent higher growth rate than its average annual rate over the period 1981-1990.[1] Annual labor productivity growth for the goods sector, in turn, averaged almost 4 percent over the period 1991-2000 compared to 2.8 percent in 1981-1990. Productivity accelerated in the service sector as well – from an annual growth rate close to 1 percent during the 1980s to about 1.7 percent during the 1990s.[2] The manufacturing sector started to experience a particularly strong resurgence in labor productivity growth in the aftermath of the recession years 1990-1993 (the deepest recession since the 1930s).

This revival in productivity during the 1990s – which is notable in comparison with the Swedish historical record dating back more than a decade – has been accompanied by a speeding up in the price decline of computer hardware and sizeable capital outlays on information and communication technology (ICT) equipment.[3] By the end of 1999, for example, the current dollar stock of business sector ICT equipment approached 16 billion – in this sector, the share of real ICT capital in total capital in-

[1] The business sector is in some studies defined exclusive of the agriculture, hunting, forestry, and fishing sectors. In this article, the business sector refers to the total business sector in the sense of market producers and producers for own final use. Note also that one potential reason why the computed productivity growth rates can nonetheless diverge somewhat between studies, although they refer to identical sectors, is that labor input is sometimes measured by the number of employees rather than worked hours. Another reason is that growth rates are sometimes approximated by log-differences. In this article, labor input is always measured by hours worked and log-differences are used for all growth rates.

[2] This resurgence in Swedish productivity was parallel to the U.S. productivity revival in the 1990s – this period has now been identified as the longest-ever-recorded period of high and sustained U.S. growth combined with low unemployment and inflation.

creased from 3.2 percent in 1993 to 5.2 percent in 1999 (see table 3 below). In the goods sector this share increased from 4.0 percent to 5.9 percent, while in the service sector it increased from 2.9 to 5.0 percent. Furthermore, the ICT capital share increased from 7.4 in 1993 to 10.1 percent in 1999 in the manufacturing sector, and, interestingly, it decreased somewhat from 32.9 to 31.3 percent in a collective ICT sector consisting of producers of high-tech goods and services.[4]

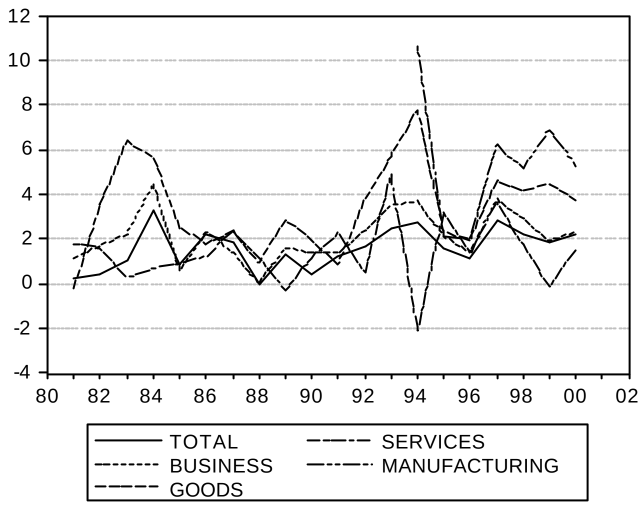

Figure 1. Average labor productivity growth 1981-2000.

Note: Total refers to the whole economy.

Source: Statistics Sweden and the author's calculations.

[3] ICT investments are defined throughout this article to include capital outlays on computer hardware (product-ISIC code 30.02) and software (ISIC 72.2) as well as telecommunications equipment (ISIC 32.1, 32.2, 32.3).

[4] This sector is defined here (and in the following) to include the manufacturing of (i) office machinery and computers (ISIC 30), (ii) cables and wires (ISIC 313), (iii) radio, television and communication equipment (ISIC 32), (iv) medical, surgical and orthopedic instruments (ISIC 331), (v) telecommunications equipment (measured by radio transmit), plus the operation of cable-television and the use of electric power (ISIC 642), and (vi) data processing and computer consulting (ISIC 72). The reason why (iv) is included in this collective measure is that substantial productivity improvements have in recent times been accomplished also in biology, pharmaceuticals, and medical technology in general – and hence it seems reasonable to take this into account when studying Swedish productivity growth in the 1990s.

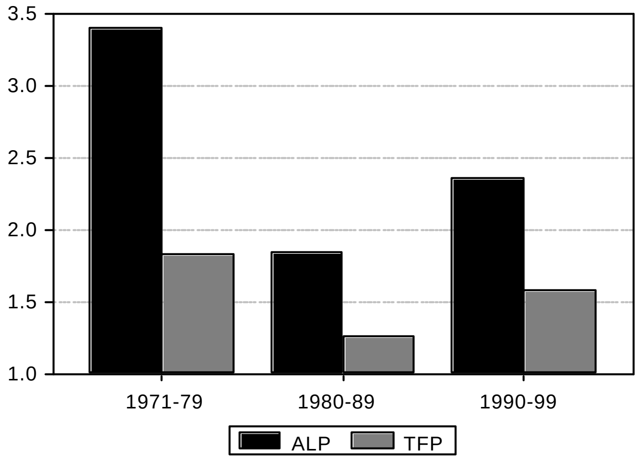

Figure 2. Business sector growth in ALP and TFP.

Note: Labor's share is set to equal 0.7. Annual average growth of ALP (TFP) has increased from 1.85 (1.26) percent 1980-1989 to 2.36 (1.58) percent 1990-99.
Source: Statistics Sweden and the author's calculations.

Table 1 shows that the Swedish business sector has – as in most other developed countries – been shifting out of goods production into services over the last 30 years. For example, the goods' share in output has declined from 40 percent in 1970 to 27 percent in 2000, and the hours worked share has at the same time declined from 47 to 29 percent. The flip side of this development is the parallel increase in the service sector's share in output (from 32 percent to 45 percent) and in hours worked (from 35 to 41 percent). Because the decline in the goods sector's share in total hours is larger than that of total output (18 percentage points as compared with 13 percentage points), the relative output per hours worked hour has increased in the goods sector (i.e. this shift in the business sector has resulted in comparatively stronger labor productivity in the goods sector). While this reorganization of the business sector has continued in the last couple of years, it has, at least to some extent, been camouflaged by the fast-growing high-tech sector in the 1990s and the recent collapse of the very same sector. Table 2 shows the shares in output and hours worked during the period 1993-1999 (thus, the impact of the ICT collapse cannot be observed in these data). According to the table, the decline (increase) of the goods (services) sector has, as expected, been less pronounced during the 1993-1999 period.

Table 1 Restructuring in the Swedish business sector 1970–2000

Share of output (GDP) and hours worked (H)

	1970		1980		1990		2000	
Sector	GDP	H	GDP	H	GDP	H	GDP	H
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Goods	40.2	47.0	33.5	38.2	31.0	32.3	26.6	28.8
Manufacturing	25.0	28.2	20.4	23.1	18.8	19.6	19.2	18.4
Construction	8.3	9.9	6.3	7.9	6.3	7.5	3.8	5.9
Other goods	6.9	9.0	6.9	7.2	6.0	5.2	3.6	4.4
Services	32.2	34.5	35.3	33.8	39.1	36.6	44.7	41.4
Wholesale and Retail	9.9	15.4	9.7	14.7	9.4	13.7	9.7	13.6
Transp. and Comm.	7.2	1.5	8.4	1.8	8.3	2.0	8.7	2.1
Finance and Insurance	0.3	1.5	3.4	1.8	5.1	2.0	3.6	2.1
Business and Real est.	10.7	2.7	11.8	5.2	14.1	7.4	19.1	10.2
Other services	4.1	5.4	2.0	3.1	2.2	3.7	3.6	5.6

Note: The output shares are computed from current SEK values. The sub-sectors are defined as follows: Goods (ISIC 01-45), Manufacturing (ISIC 10-37), Construction (ISIC 45), Services (ISIC 50-95), Wholesale and retail (ISIC 50-52), Transport and communication (ISIC 60-64), Finance and Insurance (ISIC 65-67), Business and Real Estate (ISIC 70-74).

Source: Statistics Sweden and author’s calculations.

Table 2 Restructuring in the Swedish business sector 1993–1999

Share of output (GDP) and hours worked (H)

	1993–1995		1996–1997		1998–1999	
Sector	GDP	H	GDP	H	GDP	H
(1)	(2)	(3)	(4)	(5)	(6)	(7)
Goods	28.7	29.4	28.4	29.5	27.4	29.1
Manufacturing	18.9	18.3	19.6	19.0	19.3	18.7
Electrical and optical eq.	2.3	2.2	2.7	2.5	2.5	2.5
Radio, TV, and telecom.	0.9	0.8	1.2	1.0	1.0	1.1
Services	42.1	38.2	43.0	39.1	43.6	40.0
Renting and computer	5.9	6.5	6.8	7.5	8.1	8.3
ICT	4.0	2.9	4.9	3.5	5.5	4.0

Note: The output shares are computed from current SEK values. The sub-sectors are defined as follows: Goods (ISIC 01-45), Manufacturing (ISIC 10-37), Electrical and optics equipment (ISIC 30-33), Radio, TV, and telecommunication (ISIC 32), Services (ISIC 50-95), Renting, computer, and other business activities (ISIC 71-74), ICT (ISIC 30, 313, 32, 331, 642, 72).

Source: Statistics Sweden and author's calculations.

The Swedish productivity revival has not gone unnoticed. There seems, on first consideration, to be little reason to doubt that the revival in productivity growth during the 1990s owes something to the growing high-tech sector.[5] Indeed, a number of economists now emphasize to fast capital accumulation and the latest investment boom in high-tech equipment, while others point to other factors such as genuine technological change in high-tech industries.[6] There are also economists who emphasize the usual procyclical response of productivity when output grows faster than trend. Yet others lay emphasis on enhanced methods for measuring price deflators. My reading of the empirical literature to date – for the most part based on U.S. data – is that the empirical evidence does seem to favor the argument that substantial improvements in the production of ICT equipment – typified in particular by faster and better semiconductors and rapid decline in quality-adjusted prices on ICT apparatus – has contributed right away to economy-wide gains in total factor productivity (TFP). However, although users of high-tech equipment contribute directly to ALP through high-tech capital deepening, there still appears to be difference of opinion concerning the TFP payback from the use of high-tech equipment.[7]

Recent attempts to analyze the productivity gains from ICT include, for example, Jorgenson and Stiroh (2000). Using a standard growth-accounting framework, they found that a combination of large technological improvements in high-tech sectors and the follow-on investment boom in ICT equipment are the principal driving forces behind

[5] Other potential explanations for higher trend productivity growth include, for example, the ongoing globalization of the Swedish economy and increased competitive pressure.

[6] Note that parts of the massive investments in high-tech equipment in the late 1990s were due to the year-2000 (Y2K) adaptation of computer hardware and software as well as the overhaul of commercial and financial systems.

[7] It is, of course, logically possible that the use of high-tech equipment also boosts TFP growth (and not only ALP growth) through production spillovers (e.g. learning by doing/investing) and network effects (e.g. enhanced knowledge spillovers).

behind the recent U.S. labor productivity resurgence. Oliner and Sichel (2000) confirmed this result. Jorgenson (2001) argued that the productivity growth revival is above all due to the sharp decline in ICT prices – deep-rooted in the development in semiconductor technology.[8] Gordon (2000), in turn, argued that labor productivity gains could for the most part be traced to the production of computers (thus, higher TFP growth in this production) and cyclical factors.[9] Gordon (1999) stressed that there has in fact been a labor productivity hold back in U.S. production of non-computer durable goods in the second half of the 1990s. Brynjolfsson and Hitt (2000) argued that the surge in U.S. productivity originates from over a decade of computer-generated administrative (white-collar) investments that reduce the costs of co-ordination and information processing within organizations. In addition, Stiroh (2001) found that the revival in U.S. labor productivity in the 1990s reflects both the production and the use of high-tech capital equipment. Stiroh (2002) found that high-tech capital use (ICT capital deepening) is a driving force behind more rapid U.S. labor productivity growth, as predicted by conventional economic theories, and that the effect from high-tech capital use on total factor productivity growth is negligible. This finding hence supports the view that the contribution of high-tech capital use on labor productivity operates through traditional capital deepening effects and not through higher total factor productivity growth.

In Sweden, we have so far lacked useful data on high-tech capital outlays. One exception, however, is the information on computer investments that, until 1994, were officially published every year in so-called Investment Surveys provided by Statistics Sweden. These data have been used earlier by Gunnarsson and Mellander (1999), who constructed real computer capital by combining these investment data with standard national accounts data**.** While officially published data on computer hardware and software are still in very short supply (they do not exist), this study investigates brand

[8] Jorgenson therefore pointed out that one important aim for future research is to find out the product cycle of successive generations of modern semiconductors.

[9] Gordon found that although the productivity numbers are impressive for the economy as a whole, the U.S. productivity revival appears to have occurred primarily in the production of computer hardware and telecommunications equipment (and the embedded semiconductors), including about 10 per-

new data on ICT from 1993 through 1999 (these preliminary data are provided by Statistics Sweden and are yet to be officially published and available). This additional information on high-tech capital has been produced specifically for the present analysis and the Commission on the Review of Economic Statistics. The aim of the article is twofold.

First, the principal objective of this paper is to take a closer look at the Swedish productivity revival in the second half of the 1990s. Hence, at the most direct level this paper tries to explore the productivity effects of a growing high-tech sector in the Swedish economy. In particular, I study how productivity growth in different sectors has varied from 1994 through 1999 and how these variations relate to high-tech capital formation. The second objective is to try to explain and draw attention to measurement difficulties that typically show up, and have to be dealt with, in this kind of analysis. For example, all the usual data limitations as regards the true utilization and quality of capital and labor inputs are to a great extent amplified by technical hitches associated with the computer operation time and the true cost of computer power. Conceptually, labor should, of course, be divided into hours worked and labor quality – and quality should in turn take account of, among other things, sex, age, and educational composition of the labor force. Similarly, the perfect measure of capital input should take into account the operation time (utilization rate) as well as quality differences among different types of capital. A fast-growing and, in this context, fairly new high-tech sector certainly brings with it additional data issues and, as a consequence, makes this division much more complicated.

The analysis suggests that a fairly broad labor productivity resurgence took place in Sweden during the 1990s (in the manufacturing sector, labor productivity accelerated in the second part of the 1990s) – with all principal sectors showing significant labor productivity gains in comparison with the 1980s. The analysis suggests sizeable total factor productivity growth in high-tech producing sectors and high-tech capital deep-

cent of the economy involved in manufacturing of durable goods. Gordon also stressed that the effect of ICT capital equipment on TFP growth has by and large been zero in the rest of the economy.

ening in the rest of the economy – these are findings that provide straightforward evidence of information technology's role in the Swedish productivity resurgence. In addition, for high-tech producers, high-tech capital deepening has as a rule contributed negatively to annual labor productivity growth from 1994 through 1999 – a result above all driven by large increases in hours worked in high-tech industries (this has thus resulted in a fall in ICT capital per hours worked). The analysis also documents that in the business sector, the contribution from high-tech capital deepening to labor productivity growth increased from 1.1 percent in 1994 to 9.1 percent in 1999. To my knowledge, this is the first study to document statistically the productivity effects in the Swedish economy from high-tech capital investments.[10]

Another issue is the so-called new doctrine (new economy or new era) which, as usually stated, rejects the deep-rooted idea that the risk for inflation limits the possibilities for economic growth. The new doctrine explanation for the strong run-up in share prices, for example, is faster long-term growth in the economy and the corresponding growth of corporate earnings. Although this article does not first and foremost focus on this subject, it presents some results that can be of interest when it comes to discriminating between this new doctrine and old thinking. For instance, it appears as if the Swedish productivity revival of the 1990s for the most part can be described by traditional neoclassical theory: strong total factor productivity growth in high-tech industries and high-tech capital deepening elsewhere seem to be the chief causes of the rise in Swedish labor productivity growth. High-tech firms have experienced considerable productivity gains, and other firms have responded to lower prices on high-tech capital by investing a great deal in high-tech equipment. The present analysis does not, however, explain why measured total factor productivity growth has also

[10] One earlier Swedish study in which capital is divided into high-tech and non-high-tech capital is, as mentioned earlier, Gunnarsson and Mellander (1999), who analyzed whether summation over factor inputs into aggregate input measures affects standard TFP calculations. In a related study, Gunnarsson et al. (2001) considered both high-tech and human capital when trying to determine the productivity effects of high-tech capital. In both these studies, the authors constructed their own data on computer capital by combining national accounts three-digit manufacturing data with annual investment surveys obtained from Statistics Sweden. Data on computer investments were, for an unknown reason, excluded from these surveys in 1995, implying that there is to date no officially published information on Swedish computer investments for the period 1994-2002.

been high in sectors outside of manufacturing.[11] Can it be the case that the use of high-tech capital has improved also TFP growth, or is this just a matter of coincidence that has to do with other things (e.g., the business cycle)? This question cannot be answered in this article since the short time series data preclude an adequate analysis of whether or not the use of ICT capital has also contributed to TFP growth (and not only to ALP growth through capital deepening).[12]

Much scope remains to distinguish between cyclical and structural productivity gains in the Swedish economy during the 1990s. This is, of course, of importance when it comes to getting the macroeconomic picture right – bearing in mind that Sweden escaped from a large recession in the middle of the 1990s, this distinction between fluctuation and trend may in fact seem crucial. An adequate distinction between fluctuation and trend must, however, be postponed to future work when additional time series data are available.

The organization of this article is as follows. Section 2 outlines the analytical framework. This section can be disregarded by anyone familiar with standard growth accounting. Section 3 describes the data, and section 4 presents the central empirical findings. Concluding remarks close the analysis in section 5.

2 Analytical framework

There is by now a large and growing literature on the macroeconomic implications of a growing ICT sector. The general approach in this literature is to begin by computing a measure of technological change by means of a traditional growth-accounting framework. This framework – which is simple enough to be useful, yet not disas-

[11] This finding has been reported earlier (on U.S. data) by Jorgenson and Stiroh (2000), and Oliner and Sichel (2000).

[12] These potential productive benefits from an ICT investment may show up on the inside of (internal to) the economic agent that makes that particular investment (learning by doing), or they may spill over to the outside (i.e., an external effect) to other agents in the economy (learning by others doing). Note that although some disagreement still remains about this in the literature, the most common finding seems to be that the TFP growth effect of high-tech capital deepening is very small (non-existent).

trously at odds with reality – is functional, for example, when it comes to finding out if the recent productivity upturn is broad in the sense of including the universe of sectors and if sources of productivity growth differ between producers and users of high-tech equipment.

If stronger labor productivity growth is broad, then, of course, this productivity revival is more likely to be long lasting than would otherwise have been the case. Indeed, if faster productivity growth were concentrated to a few sectors, the productivity revival would be at risk to a slowdown in these sectors. In addition, if a growing ICT sector is the prime driving force behind the productivity revival, one would probably expect to find strong TFP (and hence ALP) growth in ICT producing sectors and ICT capital deepening in other sectors. Improvement in the production of computers would, for example, show up both in a growing performance-price ratio and faster growth in TFP (ALP). Users of high-tech equipment, in turn, take action in response to falling relative prices on high-tech equipment by investing in ICT – and this also boosts ALP growth.

2.1 Comparing output and input growth

Consider a general production function $Y = F(K, L, V)$ for a single firm, where Y is value-added output (that is, gross output net of intermediate inputs).[13] Capital and labor inputs are denoted by K and L, respectively. V is an index of the level of technology. Note that beneficial spillover effects that raise overall productivity in the economy could, of course, be explicitly modeled in this context – ICT capital equipment can, for example, give rise to production spillovers and a number of network externalities. The former effect is the usual learning-by-doing (investing) effects associated with capital that tend to boost overall productivity in the economy when knowledge is

[13] I take no account in this article of the potential measurement difficulties associated with the improper use of value-added data as an output measure, even though I do not doubt that value-added may sometimes fail to account correctly for the productive contribution of intermediate inputs. True value-added output should optimally be constructed by subtracting the productive contribution of intermediate inputs (that is, energy, materials, and business services) from gross output. However, as Basu and Fernald (1995) pointed out, when the contribution of intermediate inputs is measured by factor payments, real value-added may depend directly on parts of the intermediate inputs.

non-rival and protection of proprietary information is incomplete. The latter is a new effect originating from firms investing in comparable communication equipment.

Now, let the production function F be homogenous of degree g in capital and labor, and of degree one in V. Logarithmic differentiating of F yields

$$d\ln Y = gd\ln K + \left(\frac{F_L L}{Y}\right)(d\ln L - d\ln K) + d\ln V, \qquad (2.1)$$

where $d\ln Y$, $d\ln K$, $d\ln L$, and $d\ln V$ are the growth rates of Y, K, L, and V. F_L is the marginal product of labor. I have used the homogeneity conditions $(F_K K + F_L L)/Y = g$ and $F_V V/Y = 1$ in the derivation of (2.1). This model thus compares movements in output with movements in inputs and, accordingly, relates to the growth accounting literature originating from Solow (1957). The growth rate of technology ($d\ln V$) is the Solow residual.

Equation (2.1) can be further simplified by making the assumptions that firms have some monopoly power in output markets (but not in the market for factor inputs), and that the behavior of firms can be approximated by a sequence of static problems. A simple expression for the ratio $F_L L/Y$ can be found by assuming that a representative firm (now indexed by i) faces the demand function $Y_i = (P_i / P)^{-h}(M/P)$. The price level of firm i's output is denoted by P_i, P is the general price level, M is the monetary base, and h is the elasticity of demand.

Firms are assumed to maximize the profit function $p_i = P_i Y_i - wL_i - rK_i$ with respect to labor and capital inputs in every time period. The wage rate w and the capital cost r are taken as given by the firms. The two first-order conditions are

$$\begin{aligned} P_i m^{-1} F_L &= w, \\ P_i m^{-1} F_K &= r, \end{aligned} \qquad (2.2)$$

where $m = h/(h-1)$ is the markup factor.[14] Now, let a_v denote labor's share in total value-added output, that is $a_v = wL_i / P_iY_i$, and use the first relation in (2.2) to obtain $ma_v = F_L L_i / Y_i$.[15] By combining the two first-order conditions with the homogeneity condition that $(F_K K + F_L L)/Y = g$, the product ma_v can, in turn, be rewritten in terms of the (internal) returns-to-scale parameter g and labor's share in total factor costs a_c

$$\frac{P_iY_i}{wL_i + rK_i} = \frac{m}{g} \quad \Leftrightarrow \quad ma_v = ga_c, \tag{2.3}$$

where $a_c \equiv wL_i /(wL_i + rK_i)$. Substitution of ga_c for $F_L L/Y$ in (2.1) yields the equation that is used in this study

$$d \ln Y_{it} = g_{it} d \ln X_{it} + d \ln V_{it}, \tag{2.4}$$

where dX_{it} is a weighted index of input growth

$$d \ln X_{it} \equiv a_{cit} d \ln L_{it} + (1 - a_{cit}) d \ln K_{it}. \tag{2.5}$$

The variables and parameters are now written with firm and time subscripts to emphasize that they can change across firms as well as over time.

Equations (2.4) and (2.5) can easily be re-formulated in terms of average labor productivity growth by assuming constant returns to scale and subtracting the growth rate of worked hours from both sides. After doing this, it is clear that average labor productivity growth can be divided into total factor productivity growth and the contribution from so-called capital deepening

[14] Note that no assumption of constancy of the markup factor is required.

[15] When output and input markets are competitive, the necessary conditions for producer equilibrium are that the share of every input in the value of output equals the output elasticity with respect to that input. It follows that under constant returns to scale (the elasticities sum to one) the value of output is

$$d \ln y_{it} = d \ln Y_{it} - d \ln L_{it} = d \ln x_{it} + d \ln V_{it}. \qquad (2.6)$$

Here, the growth of weighted inputs per worked hour is defined as

$$d \ln x_{it} = d \ln X_{it} - d \ln L_{it} \equiv (1 - a_{cit}) d \ln k_{it}, \qquad (2.7)$$

and

$$d \ln k_{it} = d \ln K_{it} - d \ln L_{it}. \qquad (2.8)$$

Equation (2.6) hence splits labor productivity growth into capital deepening in the sense of capital per hours worked (the more capital per hours worked, the higher is labor productivity) and total factor productivity growth (higher TFP means higher ALP). This completes the description of the model. While simple, it captures the essence of a number of different scenarios.[16]

Note that if the underlying assumptions in this model fail to hold, the Solow residual will include other things than just true technological change – for example, various distortions due to imperfect competition and spillover effects in production (see, for example, Lindström (2000)), omitted intermediate input variables due to the improper use of value-added data (see Basu and Fernald (1995)), and cyclical effects (Lindström (2000)).[17] Note also that even though various measurement difficulties may affect the Solow residual, it remains a useful indicator of pure technological change and welfare.

Broadly defined capital – which may include, for example, physical as well as human capital (human capital depends on education, on-the-job training, and research and

equal to the total cost of the production factors, and hence the share of labor in output then equals the share of labor in total factor costs.

[16] Note, however, that although this type of neoclassical analysis can illustrate what has happened in the economy as regards productivity growth it cannot explain why it happened.

[17] Note also that more thorough representations of the production process may include, for example, dynamic cost function models in which variable and quasi-fixed inputs are explicitly taken into account within a micro foundation framework. For details, see Morrison and Siegel (1999).

development) – often plays an important role in growth-accounting exercises. In the next section, tangible capital is split into three parts.

2.2 High-tech capital

In the analysis below, the real stock of capital is divided into three subgroups: (i) buildings (subscript B), (ii) machinery and equipment exclusive of ICT equipment (subscript M), and (iii) ICT equipment (subscript ICT). ICT equipment is defined to include computer hardware and software as well as telecommunications equipment. Dividing total capital into these three parts yields a detailed analogue to equation (2.7)

$$d\ln x_i \equiv b_{Bi} d\ln k_{Bi} + b_{Mi} d\ln k_{Mi} + b_{ICTi} d\ln k_{ICTi}, \qquad (2.9)$$

where the beta coefficients represent each factor's share in total cost

$$b_{ji} = (1 - a_{it}) S_{ji}, \quad j = B, M, ICT. \qquad (2.10)$$

Time subscripts have been suppressed in equation (2.9). In the present study, S_{Bi}, S_{Mi}, and S_{ITCi} are computed as the current value shares of each of the three types of capital in total capital – they hence sum to one (for more information, see section 3). Equations (2.6) and (2.9) hence capture the essence of the growth-accounting approach.

3 The data

The current data set represents a sub-sample of the officially published Swedish national accounts data from 1993 through 1999, provided by Statistics Sweden, supplemented by new time-series records on annual investments in high-tech equipment. The additional information on high-tech capital has been produced specifically for the present analysis and the 2002 Commission on the Review of Economic Statistics. The ambition is to show what can be accomplished with these new data and to give special attention to the usual problems as regards the measurement of effective factor inputs and how these problems are affected by a fast-growing high-tech sector.

The perpetual inventory method is used to compute the stock of each of the three assets buildings (subscript B), machinery and equipment exclusive of high-tech capital (M), and high-tech capital (ICT):

$$K_{jt} = (1-d^{j})K_{jt-1} + I_{jt-1}, \quad j = B, M, ICT, \tag{3.1}$$

where d^{j} is the economic rate of annual depreciation and I_{jt-1} is the gross investment in asset j in period $t-1$.

While constructing these data, special care was taken to account for differences in the depreciation rates and price deflators for computer hardware and software (see also section 4.3).

3.1 The share of capital and labor

In order to derive an indicator of firm-level input activity, dx_{it}, capital and labor are, according to (2.9), weighted by their shares in total factor costs. Total labor compensation (that is, total wage expenses, social security contributions, and mandatory insurance fees) is used here for the labor cost. Labor is measured by the number of hours worked per year.

One way to assess the user cost of capital is to follow Hall and Jorgenson (1967) – firm *i*'s user cost of asset j can then be computed according to[18]

$$r_i^j = \frac{1 - ITC_i^j - \Gamma^j}{1-t}(d^j + r - p^j). \tag{3.2}$$

[18] The user cost of capital is the price that would be charged if capital was rented for one period of time.

The economic rate of annual depreciation d^j typically lies in the interval 0.10-0.15, and the real rate of return required on capital is normally approximated by subtracting the CPI inflation rate from the required nominal and tax-adjusted rate of return on capital (that is, $r - p^j$). The investment tax credit ITC_i^j, in turn, measures the proportion of the original investment cost that is subsidized by the government. The present value of depreciation allowances for an investment is captured by Γ^j. The required payment for the jth asset then equals $r^j K^j$, where K^j is the current value of the stock of this particular asset. The total cost of employing capital in production, broadly measured as the sum of all types of capital, then equals the sum of the required payment for each of the assets. The share of capital (broadly measured) can then be obtained by dividing the total cost of capital by the sum of total capital and labor costs.

Another route is to approximate the total cost of employing broadly measured capital by the operation surplus. This surplus, which is sometimes directly available in the data at hand, is defined as the value of output net of all labor costs. Asset j's share in total costs can then be computed as

$$b_j = (1-a)\frac{K_j}{\sum_i K_i}, \quad J = B, M, ICT, \tag{3.3}$$

where a is labor's share in total costs, defined as total labor costs divided by the sum of total labor costs and the operation surplus, and K_j is the current stock value of asset j. Table 3 shows the current value shares of each of the three types of capital input in total capital. According to the table, in the business sector the share of current value ICT equipment increased from 3.2 percent in 1993 to 5.2 percent in 1999. In the goods sector this share increased from 4.0 percent to 5.9 percent, and in the service sector it increased from 2.9 to 5.0 percent. The ICT capital share increased from 7.4 in 1993 to 10.1 percent in 1999 in the manufacturing sector, and, interestingly, it decreased from 32.9 to 31.3 percent among ICT-producers. Here, this sector is defined to include manufacturing of (i) office machinery and computers, (ii) cables and wires,

(iii) radio, television and communication equipment, (iv) medical, surgical and orthopedic instruments, (v) telecommunications equipment measured by radio transmit, operation of cable-television, and the use of electric power, and (vi) data processing and computer (hardware and software) consulting. In the current analysis, equation (3.3) is used for measuring each asset's share in total costs.

Table 3 Capital stock shares

	1993	1994	1995	1996	1997	1998	1999
Business sector							
B	79,7	80,3	80,2	79,4	78,5	77,7	76,6
M	17,1	16,3	16,2	16,6	17,1	17,6	18,1
ICT	3,2	3,4	3,7	4,0	4,3	4,7	5,2
Goods							
B	57,5	58,0	57,6	56,7	55,6	54,7	53,8
M	38,5	37,7	37,8	38,3	39,2	39,9	40,3
ICT	4,0	4,3	4,6	4,9	5,2	5,4	5,9
Manufacturing							
B	40,0	40,1	39,4	38,3	37,2	36,4	35,6
M	52,6	52,1	52,2	52,8	53,7	54,2	54,3
ICT	7,4	7,9	8,4	8,9	9,1	9,4	10,1
Services							
B	88,4	88,9	88,9	88,3	87,7	87,1	86,1
M	8,7	8,1	7,8	8,0	8,3	8,5	9,0
ICT	2,9	3,0	3,3	3,7	4,0	4,4	5,0
ICT-producers							
B	53,7	54,2	53,6	52,2	51,0	50,0	48,2
M	13,5	15,3	16,6	17,9	18,8	19,6	20,5
ICT	32,9	30,6	29,8	29,9	30,2	30,4	31,3

Note: The shares are computed from real SEK values. B stands for buildings, M for machinery and equipment exclusive of ICT, and ICT for ICT equipment.
Source: Statistics Sweden and author's calculations.

Note that due to various measurement difficulties, estimates of the cost of capital are at best good approximations of the true cost of capital. It is normally safer to underestimate this cost than the opposite since capital is in general less cyclical than labor. The reason why this is safer is that spurious cyclical measurement errors in the base-line equation (2.6) are less likely to show up when labor's share in total costs is large.[19]

A closer look at data (not reported here) reveals that capital's share is sometimes pretty high (about 0.5 in 1999 for the business sector and a few percentage points smaller in earlier years). Perhaps a more plausible range for capital's share in total factor costs is about 30-40 percent (see, for example, Bentolila and Saint-Paul (1998)). I have experimented with an unvarying 30 percent capital share across all sectors without qualitatively affecting the results.

3.2 Measurement difficulties

Apart from potential stochastic measurement errors and the possible omitted-variable bias caused by simple data aggregation, one limitation of the available data is that differences in the quality of the production factors are not accounted for. In particular, the measure of labor input does not consider the distribution of competence levels among the employees. It is also rather likely that quality differences among different types of capital inputs are not satisfactorily considered even though capital inputs are split into three parts.[20] In Basu and Fernald (1995), however, similar results were obtained when using quality-adjusted workforce and capital data or non-adjusted data, suggesting that the induced error of not taking into account input qualities might not be crucial.

Another limitation is the lack of information on the factor utilization rates. Labor input is computed as the volume of labor in the sense of hours worked. Hence, this measure only matches effective labor input to the extent that it accounts for variations

[19] Yet another difficulty when it comes to computing the factor shares is that Swedish firms have occasionally been allowed to reduce their current tax payments. For example, additional tax rules have been introduced from 1980 through 1993 to subsidize firms mainly in the service sector by allowing rescheduling of tax payments equivalent to up to 20 percent of total wage costs.

[20] Note that data availability often have a strong bearing on the actual variable definitions in empirical studies of this kind. A very broad measure of capital may, for example, include capital outlays on tangible (physical) assets as well as human capital in the sense of education attainment, on-the-job training, and research and development activities.

over the business cycle in labor effort. This is, of course, hardly ever the case. Similarly, the measure of capital inputs does not take into account variations in utilization rates. It is, of course, possible that a fast-growing high-tech sector brings with it additional data problems.[21] The theoretical ideal should be input measures adjusted for quality differences as well as utilization rates.[22] A final limitation is that the data do not include information on intermediate inputs, such as energy, materials, and business services. This lack of information precludes a gross output formulation of equation (2.6).

Yet another data issue is the possibility that it may take some time for capital inputs to generate output. To allow for such delay, equation (2.6) can be modified somewhat to include lagged input variables.

4 Empirical analysis

The questions addressed in this article have some important implications for the economy as a whole. Consider for example the question of whether productivity gains have occurred in the universe of industries or just in a few of them. If productivity increases are general, the productivity revival is probably more robust than would otherwise have been the case. In addition, if the productivity increase is general, the resulting income and economic gains are distributed more equally over industries. The distribution of income – either directed evenly to all industries or just to a few of them – directly affects the well being of the employees.

[21] For discussions of other problems as regards the measurement of the contribution of computers at the macroeconomic level, see Baily and Gordon (1998), and Siegel (1997).

[22] Many studies have identified the problems associated with measuring of factor inputs. Examples are Bernanke and Parkinson (1991) who considered difficulties in the measurement of labor input when analyzing procyclical labor productivity in U.S. manufacturing, and Griliches (1994) who argued that measurement difficulties may be a major cause of the slow progress in our understanding of productivity growth. Moreover, due to difficulties in measuring input utilization rates, Benhabib and Jovanovic (1991) treated capital as well as labor as unobservable in some regressions.

4.1 Results from growth-accounting

The work reported in this section focuses on the benchmark growth-accounting relationship as described by equations (2.6) and (2.9). These expressions split labor productivity growth into capital deepening, in the sense of capital per hours worked, and total factor productivity growth. This exercise raises a few questions that, in one way or another, have been considered earlier. One concerns the nature of the data and the construction of the relevant variables. In particular, the short time series data imply that it is difficult to distinguish between cycle and trend productivity growth. Another shortcoming is that input quality and utilization rates are not accounted for. Furthermore, the benchmark equations implicitly assume constant returns to scale, which may or may not hold. However, it may certainly be a reasonable approximation, especially over longer time periods. The equations also allow for parameters varying over time and across sectors. In the analysis presented below, all cost shares are computed according to equation (3.3) – hence, these shares vary over time and between sectors.

Another issue is, as mentioned in the introduction, the question of whether or not there appears to be an empirical link between ICT use (rather than production) and gains in total factor productivity. The answer to this question determines if ICT-related capital deepening should be characterized as productive or unproductive. Indeed, during the 1990s, firms invested heavily in ICT in the hope of improving profits and productivity. Potential gains from ICT could be realized through a number of channels, such as productive spillovers and network effects due to faster information flows within and between firms. If investments in high-tech equipment really result in total productivity gains, one would expect to see a link between high-tech investment and gains in total factor productivity across industries. Such a link would allow individual industries, and hence the economy as a whole, to produce more output and thus implies a true economic benefit from the high-tech revolution. Alas, the present analysis cannot shed much light on this issue due to data limitations (too short time series data).

It is worth mentioning here that one possibility is that high-tech equipment may merely be used to reallocate the market share between the competing firms – for example when a traditional store loses business to an on-line business – or it may increase on-the-job consumption – for example, when workers play video games. Sizeable training and support costs that go along with high-tech capital outlays may also limit the productivity gains. If all of these counteracting effects are large enough, one might not see a positive link between high-tech investments and total factor productivity gains.

Table 4 Accounting for productivity growth in Sweden 1994–1999

Business (ISIC 01-95)

	1994–99	1994	1995	1996	1997	1998	1999
(1) Growth in output	4.18	4.39	5.99	1.83	3.55	4.36	4.94
(2) Growth in hours worked	1.67	2.39	3.22	0.14	–0.52	1.60	3.17
(3) Growth in ALP	2.51	1.99	2.77	1.68	4.07	2.76	1.77
(4) Capital deepening	–0.71	–1.54	–1.84	0.12	0.54	–0.52	–1.03
(5) Buildings	–0.78	–0.94	–1.51	–0.27	0.05	–0.75	–1.26
(6) Machinery excl. ICT	–0.04	–0.62	–0.39	0.22	0.36	0.12	0.07
(7) ICT	0.11	0.02	0.07	0.16	0.13	0.11	0.16
(8) TFP growth	3.22	3.53	4.60	1.56	3.54	3.28	2.80
(9) ICT share in ALP growth	5.72	1.11	2.64	9.64	3.27	3.89	9.13

Note: In 1999 the business sector accounted for 70.8 (69.3) percent of total current value GDP (hours worked) in the Swedish economy. The ICT share in ALP growth is computed as the ICT capital deepening divided by the growth of ALP.

Source: Statistics Sweden and the author's calculations.

Table 4 presents the growth-accounting results for the period 1994-1999. The first two lines show the growth in output and the growth in hours worked. The third line is the growth rate of output per hour worked (i.e., the labor productivity growth), which can be calculated in the table by subtracting the growth rate of labor hours in the second line from the growth rate of output in the first line. Labor productivity growth, in turn, can be expressed as the sum of capital deepening (line 4), which is the growth in capital per hour multiplied by capital's share in total factor costs, and total factor productivity growth (line 8). Hence, the growth rate of output per hour minus a fraction of the growth rate of capital per hour equals total factor productivity growth. Capital deepening is in turn split into buildings-related deepening (line 5), machinery-related deepening exclusive of ICT (line 6), and ICT-related deepening (line 7). Thus, the sum of line (5), (6), and (7) equals line (4). The second to last line (line 8) is total factor productivity, which is productivity growth based on a weighted average of several inputs – in this case labor and capital with weights based on the share of each input in total factor costs. The last line (line 9) shows the ICT share in labor productivity growth, computed as the ICT capital deepening in line (7) divided by the growth of labor productivity in line (3).

The main conclusions from table 4 are as follows. First, annual TFP growth was especially strong in 1994 and 1995 (3.5 and 4.6 percent, respectively), which probably has to do in part with cyclical forces – remember that Sweden escaped from a large recession in the middle of the 1990s. Second, the contribution from aggregate capital deepening to labor productivity growth is negative in 1994, 1995, 1998, and 1999. Line 5 shows that buildings-related capital deepening drives this result. A negative contribution to productivity growth from aggregate capital deepening is a rather unusual empirical finding, especially over longer periods of time. One possible reason for why capital per hours worked declined in 1994-1995 is that it represents a surge in working hours in the aftermath of the 1991-93 recession years (that is, this is a cyclical effect).[23] Other potential explanations include various difficulties concerning, in particular, the measurement of capital inputs. For example, capital per hours worked may fall as a result of the implicit assumptions that are made in the construction of the data as regards the capital depreciation rate and the price of capital. Both a higher assumed computer hardware and software depreciation rate and an underestimation of the true quality-adjusted price decline of computer hardware and software will lead to an un-

[23] The contribution from machinery exclusive of ICT was negative in 1994 and 1995, which reflects large increases in hours worked after the end of the recession. Then, as the business cycle returned to normal, investments in machinery exclusive of ICT started to increase more than hours, leaving a positive contribution from machinery-related (exclusive of ICT) capital deepening.

derestimation of the growth rate of computer capital, which, in turn, will drive down the capital-labor ratio. Third, the productivity contribution from high-tech equipment has accelerated during the period – from 0.02 percentage points in 1994 to 0.16 percentage points in 1999 (see line 7). These numbers imply that the contribution from high-tech capital deepening to labor productivity growth has increased from 1.1 percent in 1994 to 9.1 percent in 1999 (see line 9) – hence the importance of high-tech equipment for aggregate productivity growth has increased over the period. The labor productivity growth in the business sector thus appears to be driven by rising high-tech-related capital deepening as well as total factor productivity growth.

Tables 5-8 repeat this exercise for the goods sector, services sector, manufacturing sector, and ICT sector, respectively. Upon first examination of these tables there are several main findings. In particular, the productivity contribution from aggregate capital deepening is typically negative (the only exception is the manufacturing sector). Furthermore, the productive contribution from the use of high-tech equipment is in general positive and has accelerated over the period. The exception here – disregard for the moment the services sector in 1999 – is, interestingly, the high-tech sector in itself (here the high-tech share in labor productivity growth averages –5.8 percent). This probably has to do with massive increases in hours worked in this sector.[24] Another possibility is, as already mentioned, that high-tech capital may be underestimated. It is also interesting to note that TFP growth has been exceptionally high in the high-tech sector throughout the time period, an annual average of 13.1 percent as compared with 5.3 percent in total manufacturing (see tables 7 and 8).[25] The growth in labor productivity in the high-tech sector, in turn, averaged slightly more than 11 percent per year over the period – reflecting an increase in output growth of almost 19 percent per year and an increase in hours worked of slightly more than 7.5 percent. However, the size of this sector is small, implying that there is only a limited impact from labor productivity growth in this sector on economy-wide productivity growth.

[24] Note that in the ICT sector the productivity contribution from machinery exclusive of ICT is nonetheless typically positive (the annual average is 0.2 percentage points) despite large increases in hours in this sector. This suggests massive investments in machinery exclusive of ICT during the period.

[25] Note that parts of the ICT sector lie in the manufacturing sector.

Table 5 Accounting for productivity growth in Sweden 1994–1999

Goods (ISIC 01-45)

	1994–99	1994	1995	1996	1997	1998	1999
(1) Growth in output	5.09	8.70	7.30	0.65	3.36	5.07	5.46
(2) Growth in hours worked	0.87	0.89	5.00	–1.33	–1.23	0.89	0.98
(3) Growth in ALP	4.22	7.81	2.30	1.98	4.59	4.18	4.47
(4) Capital deepening	–0.03	–1.16	–2.29	1.17	1.33	0.41	0.36
(5) Buildings	–0.26	–0.43	–1.49	0.31	0.32	–0.14	–0.13
(6) Machinery excl. ICT	0.11	–0.78	–0.83	0.66	0.87	0.44	0.31
(7) ICT	0.12	0.05	0.03	0.19	0.14	0.11	0.18
(8) TFP growth	4.25	8.97	4.60	0.81	3.26	3.77	4.11
(9) ICT share in ALP growth	3.58	0.67	1.36	9.85	2.96	2.62	3.99

Note: In 1999 the goods sector accounted for 27.0 (28.8) percent of total current value GDP (hours worked) in the Swedish economy. Its share of value-added (hours worked) in the business sector was 38.1 (41.6) percent. The ICT share in ALP growth is computed as the ICT capital deepening divided by the growth of ALP.

Source: Statistics Sweden and the author's calculations.

Table 6 Accounting for productivity growth in Sweden 1994–1999

Services (ISIC 50-95)

	1994–99	1994	1995	1996	1997	1998	1999
(1) Growth in output	3.57	1.47	5.08	2.65	3.68	3.90	4.61
(2) Growth in hours worked	2.27	3.54	1.86	1.28	0.01	2.14	4.76
(3) Growth in ALP	1.30	–2.07	3.22	1.37	3.67	1.76	–0.15
(4) Capital deepening	–1.20	–2.03	–1.31	–0.68	0.02	–1.12	–2.08
(5) Buildings	–1.22	–1.55	–1.13	–0.90	–0.25	–1.23	–2.28
(6) Machinery excl. ICT	–0.08	–0.49	–0.28	0.08	0.14	0.00	0.05
(7) ICT	0.11	0.00	0.10	0.14	0.13	0.11	0.15
(8) TFP growth	2.50	–0.04	4.54	2.05	3.65	2.88	1.93
(9) ICT share in ALP growth	–12.50	–0.15	3.10	10.52	3.61	6.03	–98.1

Note: In 1999 the service sector accounted for 43.9 (40.5) percent of total current value GDP (hours worked) in the Swedish economy. Its share of value-added (hours worked) in the business sector was

61.9 (58.4) percent. The ICT share in ALP growth is computed as the ICT capital deepening divided by the growth of ALP. Note also that the annual average ICT share in ALP growth over the period 1994-99 is highly affected by the negative ALP growth in 1999; the median value of the ICT share 1994-99 is 3.36 percent, and the ICT share 1994-98 is 4.62 percent.

Source: Statistics Sweden and the author's calculations.

Table 7 Accounting for productivity growth in Sweden 1994–1999

Manufacturing (ISIC 15-37)

	1994–99	1994	1995	1996	1997	1998	1999
(1) Growth in output	7.30	13.98	9.18	2.05	5.15	6.71	6.72
(2) Growth in hours worked	1.74	3.24	7.13	–0.01	–0.97	1.42	–0.33
(3) Growth in ALP	5.55	10.75	2.06	2.06	6.12	5.29	7.05
(4) Capital deepening	0.26	–1.95	–2.56	1.61	2.16	0.87	1.41
(5) Buildings	–0.18	–0.72	–1.23	0.22	0.38	0.04	0.24
(6) Machinery excl. ICT	0.25	–1.26	–1.33	1.07	1.54	0.66	0.82
(7) ICT	0.19	0.03	0.00	0.32	0.24	0.18	0.36
(8) TFP growth	5.30	12.69	4.62	0.45	3.96	4.42	5.64
(9) ICT share in ALP growth	4.73	0.29	0.11	15.65	3.94	3.33	5.04

Note: In 1999 the manufacturing sector accounted for 19.1 (18.4) percent of total current value GDP (hours worked) in the Swedish economy. Its share of value-added (hours worked) in the business sector was 27.0 (26.6) percent. The ICT share in ALP growth is computed as the ICT capital deepening divided by the growth of ALP.

Source: Statistics Sweden and the author's calculations.

Table 8 Accounting for productivity growth in Sweden 1994–1999

Information and Communication Technology (ICT) (ISIC 30, 313, 32, 331, 642, 72)

	1994–99	1994	1995	1996	1997	1998	1999
(1) Growth in output	18.93	22.08	17.96	18.14	16.79	16.08	22.50
(2) Growth in hours worked	7.55	4.61	11.42	7.07	5.02	7.23	9.98
(3) Growth in ALP	11.37	17.47	6.54	11.07	11.77	8.85	12.52
(4) Capital deepening	–1.79	–1.43	–4.04	–0.74	–0.59	–1.69	–2.25
(5) Buildings	–1.41	–0.65	–2.60	–1.06	–0.84	–1.41	–1.93
(6) Machinery excl. ICT	0.19	0.57	–0.10	0.47	0.26	0.00	–0.10

	1994–99	1994	1995	1996	1997	1998	1999
(7) ICT	–0.56	–1.34	–1.34	–0.15	–0.01	–0.29	–0.23
(8) TFP growth	13.16	18.90	10.58	11.81	12.36	10.55	14.77
(9) ICT share in ALP growth	–5.79	–7.69	–20.5	–1.33	–0.12	–3.27	–1.80

Source: In 1999 the ICT sector accounted for 5.6 (4.1) percent of total current value GDP (hours worked) in the Swedish economy. Its share of value-added (hours worked) in the business sector was 8.0 (5.9) percent. The ICT share in ALP growth is computed as the ICT capital deepening divided by the growth of ALP.

Source: Statistics Sweden and the author's calculations.

Hence, to sum up, the key empirical finding in this section is that the Swedish productivity revival of the 1990s – as measured by the growth of labor productivity – is in part a result of a growing high-tech sector: I find sizeable total factor productivity growth in high-tech producing sectors and capital deepening associated with high-tech equipment elsewhere. The analysis moreover indicates a rising importance of high-tech equipment as a normal input in the production process, and the fact that the contribution of other capital goods has declined may in fact indicate a switch from traditional capital into high-tech capital. The potential for this substitution is likely to vary between the sectors – conceivably the ability to switch is largest for services, while in the manufacturing sector high-tech capital is typically complementary to traditional capital inputs.

Much scope remains, however, to distinguish between cyclical and structural productivity gains. Bearing in mind that Sweden escaped from a large recession in the middle of the 1990s, this distinction between fluctuation and trend seems crucial. Due to data limitations, however, I leave this to future work. Another issue is causality; note that even though the exercise above suggests that high-tech capital investments improve productivity growth, it could also be the other way around – strong productivity growth would then lead to investments in high-tech capital. Data limitations preclude a closer analysis of this as well.[26]

[26] In order to determine the causality between high-tech investments and productivity, time-series econometrics is called for, and, accordingly, longer time series are needed.

4.2 The information age

In the 1990s, a number of business economists launched what came to be known as the new paradigm (new era) economics. As regularly stated, this new doctrine abandoned the old idea that the threat of inflation would limit the possibilities for sustained economic growth. According to this view, rapid productivity growth together with increased competition and global integration would imply that even considerable growth rates would not cause any inflationary pressures. This opinion is often casually referred to as something that has to do with the new economy. The present analysis obviously relates to the above in that it investigates the productivity contribution from high-tech capital. It does not, however, go into any details as regards the variety of new era definitions that circulate nor does it in any way speculate about the future prospects of the new era and its likely effects in general on society as a whole. This lies outside the scope of the analysis. In contrast, the growth-accounting framework in the present analysis implicitly assumes traditional economic forces – and as long as the output from this exercise is sensible there is no need for tentative conjectures. Yet, taken at face value, although the results from the growth accounting exercise, saying both that total factor productivity growth has been very large in the high-tech producing sector and that high-tech capital deepening has been important elsewhere, is qualitatively in line with what most people would probably expect, one could perhaps raise objections against the magnitudes of these effects.

4.3 Future work

While allowing for preliminary data on high-tech capital and the subsequent feedback from experienced economists, the Commission on the Review of Economic Statistics makes a promising attempt to improve parts of the official statistics in Sweden. The present analysis exemplifies what can be accomplished using rather simple means and identifies some data issues that deserve additional attention. For example, the negative productivity contribution from aggregate capital deepening raises a few questions concerning the construction of the capital data: if the high-tech capital depreciation rate is too high or if the price decline of high-tech capital is too low, the growth rate of high-tech capital will be underestimated. This would hence drive down the ratio of high-tech capital and worked hours, leading to a smaller contribution to labor productivity growth from high-tech capital deepening.

Another related issue is the size of the residual in the growth accounting exercise (this part is labeled total factor productivity growth). An underestimation of the growth of factor inputs inevitable leads to an overestimation of the residual.

5 Conclusions

To summarize, the key empirical finding of this study is that Swedish labor productivity growth in the 1990s has increased in part as a result of massive investments in high-tech capital. The underlying forces seem to be pure technological improvements in the production of high-tech assets that have lowered the relative price and induced massive high-tech capital outlays. These high-tech investments have contributed immediately to labor productivity gains through high-tech-related capital deepening. More high-tech capital can work for a while, but sooner or later computer hardware and software as well as telecommunications equipment will run into diminishing returns (as will any production factor) – there are hence real limitations to this development. The finding of large total factor productivity growth in high-tech producing sectors and capital deepening associated with high-tech capital elsewhere reflects traditional economic forces such as pure technological change and factor input substitution.

Whether or not high-tech capital use is productive in the sense of improving also total factor productivity growth is still an open question – this analysis does not shed any light on this issue due to data limitations (too short time series data). The channels through which high-tech equipment logically can boost total factor productivity are many – for example, the usual productive spillovers implying that investors can benefit from embodied knowledge in capital as well as novel network effects stemming from enhanced information exchange among actors with comparable communication equipment.

Many caveats remain, however. One is the procyclical behavior of productivity. Since productivity tends to move with overall economic activity the Swedish productivity resurgence may in fact, as discussed in this article, merely reflect output growing faster than trend growth. The current analysis does not try to guess how much of the productivity surge of the 1990s reflects improvements in the underlying trend and how much is attributable to cyclical forces. Another caveat has to do with causality – whether or not high-tech equipment spurs productivity, or whether or not it is in fact just the other way around, is not analyzed in any detail. The working hypothesis thus is that the growth-accounting framework can be taken literally. Another issue concerns the methods for measuring the true cost of computer power and the underlying assumptions in the data as regards high-tech capital depreciation rate.

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