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Computers and Economic Growth in Finland

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ABSTRACT

The effect of computer technology on Finnish economic growth in 1983-96 is examined to shed light into the famous productivity paradox. Using the neoclassical growth accounting framework, the contribution of computer hardware, software and labor to gross and net output growth is assessed at aggregate level. The results suggest that a considerable amount of real growth can be attributed to computers. Almost eight per cent of the net growth can be attributed to information technology. This is about two thirds of the contribution of other fixed capital stock. However, the role of multifactor productivity still dominated in the growth accounting. In addition to basic results, the assumptions of growth accounting are relaxed to extend the model.

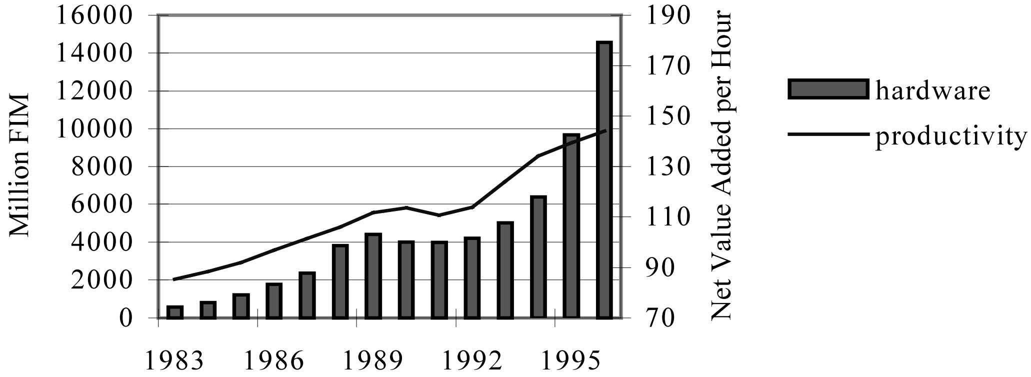
1. INTRODUCTION

Modern information technology is changing economies around the world. The recent development labeled as information revolution has been characterized by sharp decline in the prices of information processing and a rapid growth in computing power. Information technology has shaped production by introducing new production methods, such as computer-aided design and flexible manufacturing systems. Efficiency and quality of services have improved, for example, in the financial and banking sector. Companies have adopted new ways of working and have applied information technology in areas where it has not been utilized before as well as inventing products and services which would not have been possible to produce before.

The seemingly unlimited potential of computers has instigated vast investments by companies and governments in information technology. Breakthroughs in computer technology are also expected to increase the quality of life and offer new employment opportunities. The general opinion presented for instance in the business press has been optimistic about the payoffs and future gains to be achieved by information technology (Sichel 1997: 128-131). Brynjolfsson and Hitt (1996, 1997) found a high return on computer investment at the firm level and substantial contribution to consumer welfare (Brynjolfsson and Hitt 1994).

At the same time, there have been doubts about the role of information technology (IT) in improving productivity. Despite rapid computerization, productivity growth has not exceeded the trend and cannot be linked to increases in computer investment in the last few years. Figure 1 shows the acceleration in computer hardware investment in the 1990s along with labour productivity in the nonresidential business sector. Labour productivity is measured as the ratio of net value added in 1990 prices and hours worked. In recent years, productivity has not followed the rapid growth in computer investment. Solow (1987: 36) and Baily and Gordon (1988) have referred to this phenomenon as productivity paradox. A number of studies have found that computing equipment has earned a low rate of return on investment [i.a. Osterman (1986), Loveman (1995) and Morrison and Berndt (1991)]. Oliner and Sichel (1994) provide the small size of computer capital as an explanation for the productivity paradox.

FIGURE 1
COMPUTER HARDWARE INVESTMENT AND LABOUR PRODUCTIVITY
IN FINLAND,1983-96



Since an increase in productivity or output growth is the ultimate source of economic well-being of a nation, the effect of information technology in economic growth is the crucial question. Are the impacts of information technology on productivity different from such technological advances in the past as railways or electricity? In order to answer this question, the effect of computer technology on economic growth should be assessed thoroughly.

The second question is related to policy issues. In Europe and in the USA, a large scale effort is about to be embarked to develop the so-called information superhighway. Companies continue to invest in increasingly powerful hardware and software,along with households buying computers and connecting to the Internet. For policy makers, managers and general public it is vital to have realistic expectations about the size of the aggregate economic boost to be attained from information technology. If information technology has helped to achieve productivity gains, allocation of funds to computers could produce encouraging results for the economy. However, if the gains in productivity do not correspond to the current investment trend, resources could be allocated to other targets.

We attempt to answer the questions above by analysing the effect of information technology on output growth. We begin with a growth accounting framework to compute the contributions of capital, labour and multifactor productivity. Subsequently, capital is divided into computer hardware and other capital. To this end, computer capital stock is formed.

Since computer hardware cannot be used alone, the framework is extended to include software and computer labour, two other components of computer services.

The results indicate that the effect of computing technology on economic growth has been considerably high, especially if the share of computer equipment in the total capital is taken into account. Despite the fact that computer hardware accounts for only two per cent of the net capital stock in Finland, its contributing share to net output growth has been approximately 50 per cent of the contribution of other physical capital. After extending the model to include software and computer labour in the growth accounting framework, the contribution of IT grows by one-third. Over the period 1983-96, the average annual net growth in Finland was 2.4 per cent, of which nearly 0.2 percentage points can be attributed to information technology.

The outline of this paper is the following. The methodology of neoclassical growth accounting is presented in section two. Data and empirical questions are dealt with in section three, followed by results in section four. The assumptions of the neoclassical model are relaxed in section five. Section six concludes the paper.

2. METHODOLOGY

In the standard neoclassical growth accounting framework, the contribution of an input to output growth depends on the income share and the growth rate of the input. The assumptions behind the Denison-style growth accounting are the following. First, there are constant returns to scale in production. Second, input markets are competitive. Third, there are no externalities. Some of these assumptions are relaxed later but first we begin with the standard framework.

Let the production function be

(1) $$Y = F(K, L, T)$$

where K and L denote capital and labour, and T represents disembodied technological change or, in other words, shifts in the production function over time. The second assumption above implies that the marginal product of each input X_i $(\partial F/\partial X_i)$ equals its real rental price (r_i/P), that is, input price divided by a general price index. Third assumption ensures that social and private marginal products are equal. The standard growth accounting equation can be obtained by differentiating equation (1) with respect to time and dividing by Y:

$$(2) \qquad \dot{Y} = \sum_i s_i \dot{X}_i + \dot{MFP}$$

where s_i depicts the income share of an input i, and MFP $(=(\partial F/\partial t)/Y)$ stands for the multifactor or total factor productivity. The growth rate $\dot{X}_i$ for an input is defined as the natural logarithmic annual change in the use of the input. Above the income shares s_i equal r_iX_i/PY and, using the first assumption, income shares add to one.

3. EMPIRICAL APPLICATION AND DATA

In the empirical application, information technology inputs will be separated from the traditional inputs K and L. For instance, the contribution of physical capital is divided into the contribution from computer hardware and other physical capital:

$$(3) \qquad s_c \dot{K}_c + s_K (K - \dot{K}_c)$$

where subscript c and k denote computer hardware and other capital, respectively. Income share for computers (s_c) is unobservable. However, if the rental rate and investment in computing equipment are known, income share can be estimated.

The effect of declining prices is taken into account in a more precise definition of the real rental rate r. In the case of computer hardware, the net rental rate consists of i, the competitive rate of return on fixed capital, depreciation rate δ and the change in computer price index p_c:

$$(4) \qquad r_c = i + \delta - \dot{p}_c$$

Defined this way, the rental rate incorporates the part of return required to compensate for the deterioration of capital. It also includes the profit (loss) stemming from a increase (decrease) in the input price. For instance, if the price of capital increases, the firm benefits from having acquired it earlier, prior to the increase in price or its rate of growth. Negative capital gains are sometimes used for the last two terms, since these describe better the technological deterioration which for computers is more appropriate than physical wearing out.

Since a firm solves the optimal choice of inputs every year by comparing the current input prices, the use of input X_i can be expressed in nominal terms: p_iK_i for the capital stock of input i or p_LL for labour input. For computer hardware, the income share becomes

$$(5) \qquad s_c = \frac{\left(i + \delta - \dot{p}_c\right) p_c K_c}{pY}.$$

For growth accounting, data for output Y and inputs X_i are needed, along with price indices to obtain real growth rates. The variables are compiled from a number of time series. The capital used by government and households is omitted in growth accounting since it does not contribute to the measured output in these parts of the economy (see e.g. Denison 1985). Thus, the scope of the study is the private nonresidential business sector excluding farming. This applies to all variables in the model. For instance, the labour input does not include labour in agriculture, public sector and residential sector.

The key variables in the growth accounting model are now briefly described. The growth rates in the study are measured as natural logarithmic changes. When year-by-year changes are measured, the annual change is defined as $ln(X_t)-ln(X_{t-1})$.

3.1 Output

Output Y is defined as value added at producer price. Both gross and net outputs are calculated, the latter being defined as gross value added minus depreciation for each year. Note that the denominator in equation (5) is given in nominal terms. When income shares are computed, the denominator is either gross or net nominal output, depending on whether we look at gross or net output growth.

3.2 Labour

Labour input depends on the quantity and the quality of labour. The former is measured by labour hours. Labour costs consist of wages and payroll taxes. These are needed to calculate the income share of labour input. The real growth in labour input is measured by the change in total hours worked. The income share of labour is denoted by $s_L = P_L L / P_Y Y$, where Y is either gross or net value added, depending whether we analyse contributions to gross or net output.

The changes in the quality of labour should be incorporated in the labour input calculation. Factors affecting the quality of labour input include various demographic variables such as age and education. We assume that labour markets are competitive, that is, marginal product of an employee equals his wage. Therefore, the variations in wages stemming from differences in age and education can be used to create a proxy for qualitative changes. For instance, if the educational level of employees rises and employees with higher education earn a wage premium, the quality of labour input has increased. Age can be seen as a proxy for experience. Also the gender of an employee can give rise to wage premiums even though it is not easily compatible with the theory of efficient labour markets.

We use education to capture the quality changes in labour input. Of the above mentioned variables, educational level has changed the most during our observation period of 1983-96. The age structure and the participation of women in the work force have been quite stable in that period. Thus, education is a suitable variable for measuring changes in the quality of labour input. For this purpose, we create a quality index for labour. The index takes changes in educational level into account. It is described in detail in appendix I.

The rise in educational level accounts for some of the increase in the quality of labour. However, it fails to capture for example learning by doing. Learning at the workplace probably occurs if an employee receives a raise after beginning to use a computer at work. Wage premiums for computer utilization have indeed been reported – this will be discussed in section five. Part of the wage premium for education can be explained by the increase in computer usage. According to Krueger (1993), almost 40 per cent of the return on schooling stems from increased computer use. This is captured by the above estimates. However, installation of computers also affects efficiency through new working methods and improved skills. This is reflected in the wage premiums of all computer-literate employees irrespective of their educational background. Later we will discuss the direct effect of computer use on labour productivity.

3.3 Capital

Capital stock is defined as net capital stock. The growth rate of the capital input is based on the growth rate of net capital stock. In growth accounting results for both gross and net output growth are calculated. Note that in both cases, net capital stock is used. Gross capital stock includes accumulated depreciation and is not needed in the calculations. Its absolute value is about three times higher than the value added in nonresidential business sector at producer price.

Residential capital is omitted from capital stock for the reasons explained above. The income share of capital is retrieved as residual (see e.g. Dollar and Wolff 1993: 67-8). It equals

$$s_K = 1 - s_L.$$

In the basic model with only *L* and *K* as inputs, the above income shares add to unity. In the extended growth accounting models, the above condition is also imposed before including additional inputs.

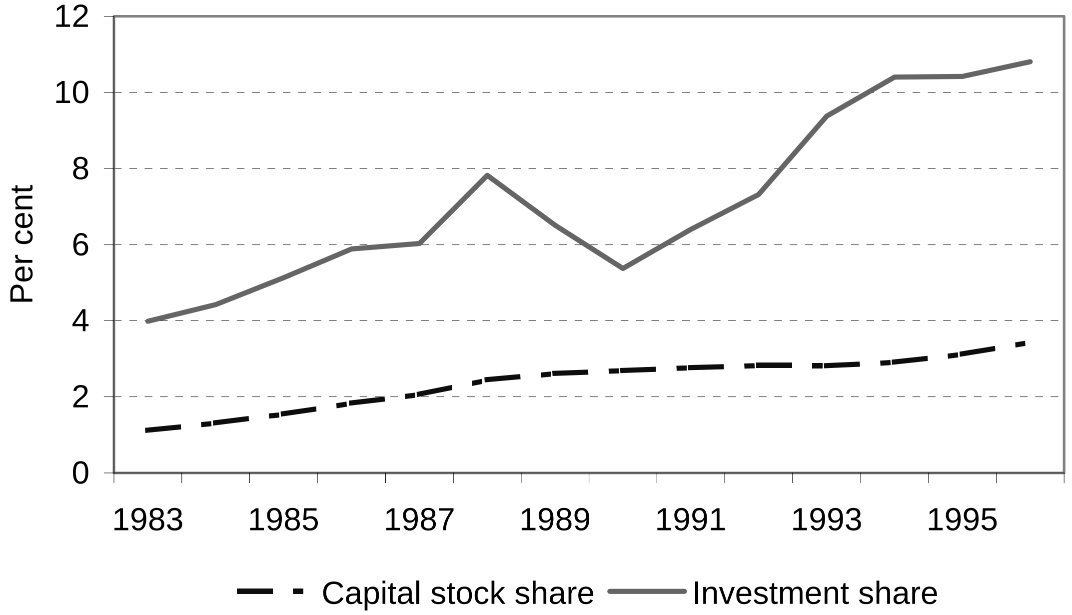
3.4 Computer hardware and software

Due to data restrictions, empirical studies on the investment in information technology have been carried out mainly with US and Canadian data. Statistical authorities in Finland have not systematically collected data on information technology investment. The government has compiled statistics only on its own investment. In Finland, only International Data Corporation (IDC) has collected investment data on the whole economy.

Computer capital series for both hardware and software are constructed from the investment series obtained from IDC Finland. These series represent the sales of computing equipment in Finland and include both the private and public sector. Since the purchase of computer equipment and software is increasingly decentralized in companies, an inquiry among information technology departments is a less reliable method than getting sales figures directly from the distributors. The IDC time series cover the sales of computer hardware, software and computer services since 1983.

Purchases by the government and municipalities (about 20 per cent of all sales) are subtracted from the investment series to obtain figures for the business sector. Figure 2 illustrates the share of computer investment in non-residential investment and the share of computer capital in the total non-residential capital stock in the Finnish business sector.

FIGURE 2
COMPUTER SHARES IN NON-RESIDENTIAL INVESTMENT
AND IN CAPITAL STOCK IN THE FINNISH BUSINESS SECTOR, 1983-96
(%)



Data on government and municipality investment in information technology are obtained from Information Technology in the government annuals and from the Association of Finnish Local and Regional Authorities. Detailed information on municipalities' investment is available from 1989. Estimates for earlier years have been based on the assumption that the ratio between municipalities' and government's investments has been the same as in the period of 1989-96 in each category of IT outlays. The average investment share of the private business sector in 1983-96 has been 80 per cent, while average investment shares of municipalities and the government have been 11 per cent and 9 per cent, respectively.

Capital stocks for hardware are constructed by applying a distribution of depreciation factors. Oliner (1993) estimated a depreciation profile which can be used as weights to calculate net computer capital stock in a given year. This profile is also used by the Bureau of Economic Analysis (BEA).

We construct the Finnish net stocks using the same distribution of depreciation rates. On average, computer hardware net stock accounted for 2.5 per cent of the total physical capital net stock in the business sector. This is in line with the survey conducted by Statistics Finland in 1991, where office computers accounted for two per cent of the fixed capital stock in industry (*Teollisuuden käyttöomaisuus ja teknologia* 1990: 7). It is reasonable to assume that the share of computers should be somewhat higher once the service sector is included. In the USA, estimates for the share of computers are about the same: 2.1 per cent of total net capital stock in 1990 (Oliner and Sichel 1994: 279) or 2.1 per cent in large corporations in 1987 (Brynjolfsson and Hitt 1996: 549).

For the sake of comparison, we calculated net stocks with a straight line depreciation of 25 per cent. The 1983 capital stock is calculated based on the assumption that in 1957-83 investments grew at the same rate as during the observation period. 1957 is the base year because the first computer was acquired in Finland that year (www.valt.helsinki.fi/atk/kirja/laskenta/yleista.htm). According to the perpetual inventory method, the net stock is a little smaller - 2.0 per cent of the physical capital net stock. On the other hand, the growth rate of real net stock is higher than in the stock created by Oliner (1993) depreciation profile.

Software stock is calculated with a perpetual inventory method utilizing a depreciation rate of 25 per cent. This figure is used also by Oliner and Sichel (1994). The net stock for 1983 is computed as in the case of hardware.

In order to estimate income shares for hardware and software inputs, the rental rate for computing equipment needs to be estimated. This is represented by $(i + \delta - \dot{p}_c)$ in equation 5. The last two terms depict the rate of decline in the asset's market value resulting from deterioration and obsolescence caused by a decline in quality-adjusted prices. For the latter, the (BEA) hedonic price index for computing equipment has become almost the norm for adjusting computer prices to quality changes. The BEA price index has also been the key factor behind the decision in the USA to switch from fixed weights to chain-weighted index in calculating growth in GDP and industrial output (OECD 1997: 77).

The BEA computer equipment price index was introduced in 1985. The IBM-BEA hedonic index was the original price index designated for mainframe computers. Later, other indices have been created for disk and tape drives, terminals, PCs and printers. For the years from 1982 onward, BEA has updated samples, re-estimated hedonic regressions and computed price indices using the same methodology. This method is referred to as ”matched model with hedonic imputation of missing prices”. The hedonic function is used to impute a price when a particular computer model is present in one year but missing in another. However, no imputation is needed when a computer model is present in both years for which an index is compiled (Triplett 1996: 17-19).

FIGURE 3
PRICE INDEXES (1990=100) WITH AND WITHOUT QUALITY ADJUSTMENT

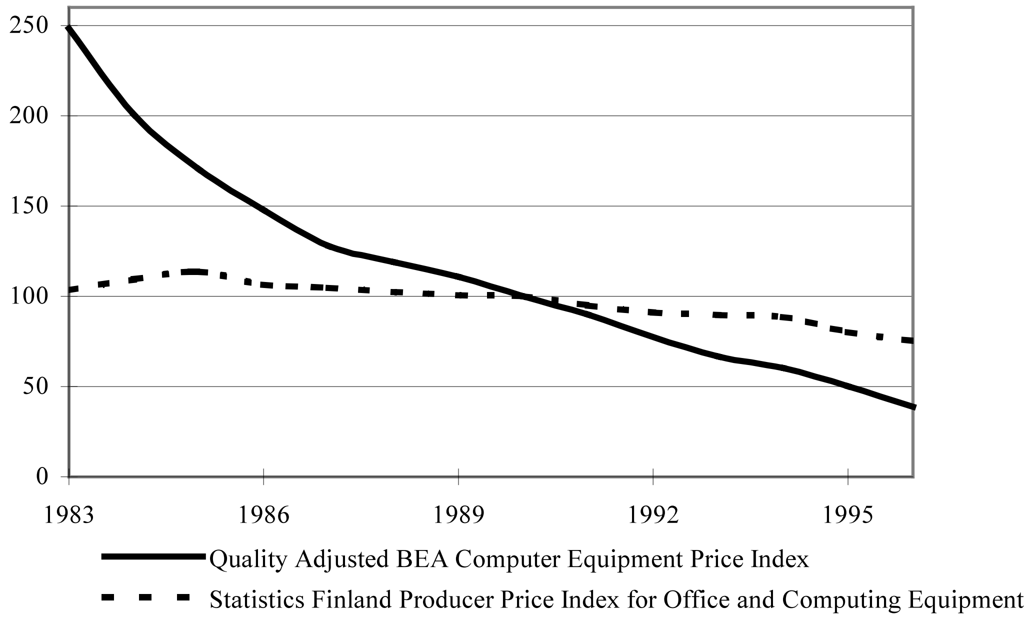


Figure 3 illustrates the drastic decline in quality-adjusted prices for computing equipment. The BEA hedonic price index was available till 1994 (Triplett 1996: 36). For 1995 and 1996 the index has been supplemented with the Bureau of Labour Statistics producer price index for SIC357 (office, computing and accounting machines). The BLS index is also quality-adjusted (see e.g. Sinclair and Catron 1990, and www.bls.gov).

Oliner and Sichel (1994: 284) estimated the combined effect of $(\delta - \dot{p}_c)$ to have averaged 24.3 per cent annually in 1970-92. This is based on the BEA data. Unfortunately, there is no quality adjusted computer or software price index for Finnish data. Thus, we have to assume that computer prices have followed the same declining trend as in the USA.

According to European Information Technology Observatory (EITO 97: 293-294), in the 1990s price dynamics in Europe very closely followed the developments of the USA two years after the introduction of a new PC generation. Also, there has been a lag before new models have penetrated the European market as can be seen in Figure 4. Furthermore, Kotola (1994: 62) estimated that the prices of PCs decreased 19.9 per cent a year in 1991-93. The study was based on a matched model estimation with student or academic prices. During the same period, the BEA computer index declined 17 per cent annually. Therefore, it is reasonable to assume that the price dynamics do not differ greatly in the long run. In our calculations, we have used a value of 25 per cent for $(\delta - \dot{p}_c)$ in the benchmark case. In order to illustrate the effect of quality adjustment in computer prices, an alternative estimation has been carried out with a non-hedonic price index. Summarized results can be found in appendix II.

The parameter value for the net rental rate *i* equals 10.0 per cent. This is the average long term interest rate in Finland for the 1983-94 period according to the OECD Economic Outlook.

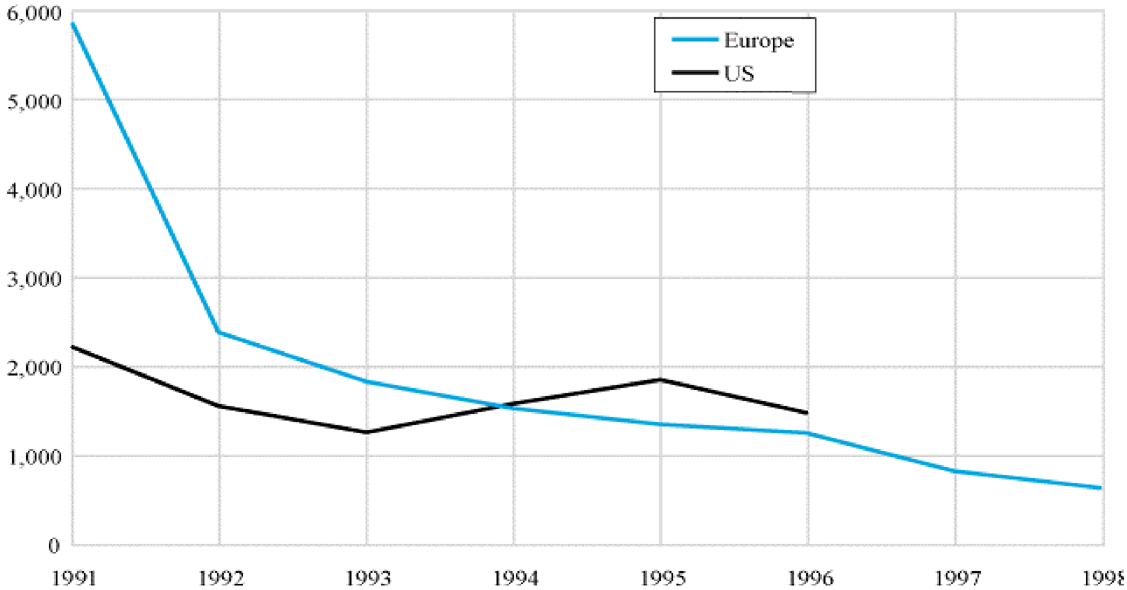
For net output growth accounting, the effect of $(\delta - \dot{p}_c)$ is dropped since the required return on investment is now only *i*:

$$s_c = \frac{i\, p_c K_c}{pY}$$

Note that we get an income share for each year. Average income shares in 1983-96 for net and gross hardware stock were 0.5 and 1.4 per cent, respectively. When the contribution from hardware is computed, the income share is taken as an average of two years: $[s_c(t)+s_c(t-1)]/2$. Income shares s_c are then multiplied by the annual growth rates $ln(X_t)-ln(X_{t-1})$. Subsequently, the average contribution can be computed as the arithmetic average over the years.

Alternatively, we could calculate the contribution by multiplying the average income share by average annual growth rate calculated from the first and the last year. The results are robust in the sense that the differences between these methods are negligible.

FIGURE 4
CONVERGENCE OF AVERAGE SELLING PRICES FOR 486DX PCS
(US VERSUS EUROPE), ECU, 1991–98



Source: EITO 97: 294.

3.5 Computer labour

Computer services include maintenance, support services, consulting and training. We treat the cost of computer services as a measure of computer labour input. The share of computer services in total labour costs is slightly lower than the share of computer hardware in total fixed capital stock. In 1983-96, the value of computer services has been on average 1.7 per cent of total labour costs.

The average shares of hardware, software and computer labour in total IT investment in the private business sector were 47, 39 and 14 per cent, respectively. The share of hardware has remained stable throughout the observation period while the share of software has doubled to 16 per cent in 1996, thus curtailing the share of services.

In contrast to total labour input, labour hours for computer services are not available and quality adjustment cannot be done. Hence, real growth in computer labour input is measured by the change in real computer labour costs. These are obtained by deflating the costs of computer services by the index of wage and salary earnings published by Statistics Finland.

Subsequently, the contribution of computer labour to output growth is calculated similarly to the contribution of hardware and software.

In the growth accounting model with computer services included as an input, total labour input is adjusted accordingly. The nominal cost of computer services is subtracted from total labour costs. This lowers the income share of labour input *L* by about a percentage point. The growth rate of *L* computed above is based on total hours worked and quality adjustment. Therefore, the growth rates of total labour input and computer labour input are based on different measures – labour hours and costs, respectively. As a result, the measure of growth rate for *L* has been left unchanged when computer labour is included in the model. This overstates the growth rate of labour input a little. The effect is probably negligible: if average real growth rates of total labour costs with and without the computer labour are compared, the difference is a few hundredths of a percentage point.

4. RESULTS

The entire period is divided into two subperiods – the 1980s and the 1990s. Thus, the first phase covers the years 1983-90 and the second 1991-96. The first period is characterized by high output growth, averaging four per cent annually. The second phase includes the recession in the Finnish economy, with the average growth rate barely evident.

To begin with the growth accounting analysis, a basic model with only labour and capital inputs is computed. Table 1 presents the results.

The income share of capital is approximately 40 per cent in gross output growth and 28 per cent in net output growth over the period 1983-96. Net output is a more appropriate measure of economic well-being than gross output since investments in physical capital to offset depreciation do not increase welfare as such. In Finland the income share of capital is internationally high, e.g. in the USA the gross income share is around 30 per cent compared to 40 per cent in Finland (Sichel 1994: 285).

TABLE 1
CONTRIBUTIONS TO GROWTH OF REAL OUTPUT 1983-96,
BASIC MODEL WITHOUT INFORMATION TECHNOLOGY

		GROSS			NET		
		1983-96	1983-90	1991-96	1983-96	1983-90	1991-96
output growth[1]		2.38	4.01	0.47	2.36	4.06	0.39
contributions[2]	K	0.32	1.18	-0.67	0.26	0.86	-0.44
	L	-0.73	0.29	-1.93	-0.91	0.34	-2.37
	MFP	2.79	2.55	3.06	3.01	2.86	3.20
income shares[1]	K	39.5	39.0	40.2	27.6	28.3	26.7
	L	60.5	61.0	59.8	72.4	71.7	73.3
growth rates[1]	K	0.9	3.0	-1.6	0.9	3.0	-1.6
	L	-0.9	0.5	-2.8	-0.9	0.5	-2.8

[1] per cent
[2] percentage points

The recession at the turn of the decade had a strong effect on results. Both labour costs and the stock of physical capital declined in Finland in the 1990s. This decline offsets the growth of the 1980s in these inputs. For example, the quality adjusted index for labour input declined from 99.2 in 1983 to 86.6 in 1996. Real net capital stock rose from FIM 516 billion in 1983 to 638 billion in 1990 but dropped to FIM 607 billion in 1996.

The average annual growth rate of real capital stock, 0.9 per cent, has been quite low in Finland compared, for example, to the USA where in 1980-92, it was on average 3.0 per cent per annum (Sichel 1997: 77). However, the recession of the 1990s has affected labour input even more. Whether measured by labour hours or total labour costs, the growth of labour input has been negative during the whole period, even after adjusting for the quality of labour input. Labour hours in the business sector did not increase even in the 1980s. As a result, the contribution of labour is negative to real output growth. The contribution of capital also remains at a low level, accounting only for 0.3 percentage points of the growth of 2.4 per cent. Combined with the negative contribution of labour input, this makes the contribution of MFP over hundred per cent of the output growth. Even during the boom of the 1980s, about 60 per cent of the output growth can be attributed to the MFP.

The basic model is extended by subdividing physical capital into computer hardware stock and other fixed capital, that is, hardware stock is subtracted from the capital stock. Note that the income share for other capital is calculated as before. It adds to unity with the income share of labour input.

Subsequently, the income share from computer hardware is added, and finally, the sum of the three income shares is scaled to equal one. Hence, the income shares from hardware and other physical capital do not add exactly to the income share of capital in the basic model. The results from the extended growth accounting model are presented in Table 2.

TABLE 2
CONTRIBUTIONS TO GROWTH OF REAL OUTPUT 1983-96,
A MODEL WITH COMPUTER HARDWARE

		GROSS			NET		
		1983-96	1983-90	1991-96	1983-96	1983-90	1991-96
output growth[1]		2.38	4.01	0.47	2.36	4.06	0.39
contributions[2]	hardware	0.38	0.42	0.33	0.13	0.14	0.11
	K	0.32	1.14	-0.64	0.26	0.86	-0.44
	L	-0.73	0.29	-1.91	-0.90	0.34	-2.35
	MFP	2.41	2.17	2.69	2.88	2.72	3.06
income shares[1]	hardware	1.7	1.3	2.1	0.6	0.4	0.7
	K	38.0	37.7	38.3	27.5	28.2	26.5
	L	60.3	60.9	59.5	71.9	71.4	72.7
growth rates[1]	hardware	24.7	32.3	15.8	24.7	32.3	15.8
	K	0.9	3.0	-1.6	0.9	3.0	-1.6
	L	-0.9	0.5	-2.8	-0.9	0.5	-2.8

[1] per cent
[2] percentage points

Given that computer hardware makes up only 2.5 per cent of the net capital stock in Finland, the contribution from computers to output is remarkable. Of the gross output growth in 1983-96, the contribution of computers is almost 0.4 percentage points, higher than that of other fixed capital. Hardware accounts approximately for 16 per cent of gross output growth. The underlying reason can be found in the rapid increase in computer capital stock. The average annual growth rate has been 24.7 per cent, similar to that in the USA in 1980-92 (Sichel 1997: 77). Combined with slow or even negative growth rates of labour and other capital, the share of computers in output growth becomes large.

At 5.5 per cent, the contribution from hardware to net output growth is smaller due to the rapid depreciation of net computer capital stock. The contribution is slightly higher than the 3.8 per cent found in the US in 1987-93 (Sichel 1997: 80).

Since computer hardware cannot be used without software and maintenance, the total effect of information technology should be calculated using a broader definition. In the spirit of Oliner and Sichel (1994), we extend the model by adding computer software and computer labour to estimate the total input of information technology. As before, the income shares for capital and labour are first scaled to unity, then other inputs are added to the model and scaling is repeated. The results can be found in Table 3.

TABLE 3
CONTRIBUTIONS TO GROWTH OF REAL OUTPUT 1983-96
A MODEL WITH INFORMATION TECHNOLOGY

		GROSS			NET		
		1983-96	1983-90	1991-96	1983-96	1983-90	1991-96
output growth[1]		2.38	4.01	0.47	2.36	4.06	0.39
contributions[2]	total IT	0.47	0.52	0.42	0.18	0.21	0.15
	hardware	0.38	0.42	0.33	0.13	0.14	0.11
	software	0.07	0.05	0.10	0.03	0.02	0.03
	comp.labour	0.02	0.04	0.00	0.03	0.05	0.00
	K	0.32	1.14	-0.63	0.26	0.86	-0.44
	L	-0.71	0.28	-1.87	-0.89	0.33	-2.31
	MFP	2.30	2.08	2.55	2.81	2.66	2.99
income shares[1]	hardware	1.7	1.3	2.1	0.6	0.4	0.7
	software	0.3	0.1	0.5	0.1	0.0	0.2
	comp.labour	1.0	1.0	1.1	1.2	1.1	1.4
	K	37.9	37.7	38.2	27.5	28.2	26.5
	L	59.1	59.9	58.1	70.6	70.2	71.2
growth rates[1]	hardware	24.7	32.3	15.8	24.7	32.3	15.8
	software	32.0	40.5	22.1	32.0	40.5	22.1
	comp.labour	2.3	4.4	-0.2	2.3	4.4	-0.2
	K	0.9	3.0	-1.6	0.9	3.0	-1.6
	L	-0.9	0.5	-2.8	-0.9	0.5	-2.8

[1] per cent

[2] percentage points

The effect of information technology on growth is considerable during the observation period. In the boom years, about 0.5 percentage points of the 4 per cent gross output growth can be attributed to computer services (= hardware + software + computer labour). This is one-third of the combined effect of other capital and labour. In percentage terms, the contribution of IT is 19.7 per cent to the gross output growth in 1983-96. This is similar to the Sichel (1997) result, where the contribution was 16 per cent over the period of 1987-93.[1] Over the whole period, the role of IT is more pronounced since labour input has a negative contribution.

In the net growth accounting, the contribution from IT is smaller. In the 1980s, 5.2 per cent of the net output growth can be attributed to information technology. Since depreciation affects IT more than other physical capital, the contribution of IT is now only 18 per cent of the combined contribution from other capital and labour.

In the whole period, the contribution of IT is around 8 per cent of the net output growth. Again, this is very close to the estimate by Sichel (1997: 80), who found that computer services contributed approximately 9 per cent, or 0.15 percentage points to an average annual net output growth of 1.6 per cent in 1987-93. Even if the share of IT is not as high in net growth as in gross growth accounting, computer stock still has a disproportional effect compared to its share of fixed capital stock. Table 4 summarizes the results of IT for Finland and the US.

The role of multifactor productivity is still considerably high in all periods, constituting at least half of the real output growth but exceeding the output growth rate especially in the economic downturn. In the Oliner and Sichel (1994) study on US data, the contribution of multifactor productivity ranged from 15 to 30 per cent of the output growth. The problematic business cycle is probably the biggest reason for the difference between the US and Finland.

A notable difference between the Finnish and US results can be seen in the income shares of the IT components. The income shares of computer labour are about equal in both countries (Sichel 1997: 80). This holds true for both gross and net growth accounting. However, the income shares of software and hardware differ considerably between the US and Finland.

A closer look at the contribution of computer hardware reveals that growth rates are about equal in the US and Finland. However, the income share of hardware is about twice higher in Finland than in the US. In 1987-93, the income shares in the US were 0.9 and 0.3 in gross and net growth

[1] Due to data restrictions, Sichel was able to estimate the effect of total information technology only for the subperiod 1987-93 (Sichel 1997: 80).

accounting, respectively. This explains the differences between the contributions of computer hardware in the two countries.

TABLE 4
IT CONTRIBUTIONS IN FINLAND AND IN THE USA

		Finland 1983-96				USA 1987-93*			
		GROSS		NET		GROSS		NET	
output growth[1]		2.38	%[3]	2.36	%[3]	2.0	%[3]	1.6	%[3]
contributions[2]	total IT	0.47	*19.7*	0.18	*7.6*	0.31	*15.5*	0.15	*9.4*
	hardware	0.38	*16.0*	0.13	*5.5*	0.15	*7.5*	0.06	*3.8*
	software	0.07	*2.9*	0.03	*1.3*	0.11	*5.5*	0.04	*2.5*
	comp.labour	0.02	*0.8*	0.03	*1.3*	0.05	*2.5*	0.05	*3.1*
income shares[1]	total IT	3.0		1.9		2.4		1.4	
	hardware	1.7		0.6		0.9		0.3	
	software	0.3		0.1		0.7		0.3	
	comp.labour	1.0		1.2		0.8		0.9	
growth rates[1]	hardware	24.7		24.7		17.2		17.2	
	software	32.0		32.0		15.3		15.3	
	comp.labour	2.3		2.3		6.0		6.0	

[1] per cent

[2] percentage points

[3] per cent of output growth

* Source: Sichel 1997: 80

The composition of the income share for hardware is given in equation 5. The first term in the numerator, the net rental rate, is about equal in Finland and the US. Also K_c/K is nearly the same, implying that the difference between the income shares can be attributed to the ratio of p_cK_c/pY. The explanation is related to the high capital intensity in Finland. Since K/Y is higher in Finland than in the US, the same applies to K_c/Y. This ratio has doubled in Finland every five years since the early 1980s.

4.1 Other components of information technology

Information technology is a rather vaguely defined concept. In the above, we have included hardware, software and computer services in IT. Sometimes office equipment other than computers is included in IT as well. This group consists of photocopiers, calculators, accounting machines, mail handling equipment, etc. Another large component often included in the definition of IT is telecommunications equipment.

Investment in non-computer office equipment has lost ground to computer investment in the last decade. Investment figures cannot be obtained directly, but the Association of Office Technology Trade has compiled time series from customs statistics. These represent the import of office equipment and computers in Finland in 1990-96. The computer import series can be compared to the investment series of IDC. In the 1990s, the import series fluctuates between 67 and 117 per cent of the investment series, the average being 91 per cent. The fluctuation probably stems from variations in the stocks of sellers. On average, the series are quite similar. Thus, for our purposes, little is lost by taking the imports of non-computer office equipment as a proxy for investment in that category.

In the 1990s, imports of non-computer office equipment have been on average 14 per cent of the imports of computers. The income share of this small component of IT is therefore estimated to be 14 per cent of hardware's income share. The nominal import series are deflated by the office equipment index of Statistics Finland to retrieve the approximated investment series. Using a steady-state assumption, we use the growth in imports as an estimate for the growth in net capital stock. Naturally, this would require that imports have grown at a constant rate. Therefore, the calculated contribution is just a rough estimate of the magnitude of non-computer office equipment.

The average rate of net growth in non-computer office equipment has been barely evident at 0.9 per cent a year in the 1990s. Given the small income share, the contribution to gross and net output growth in the 1990s remains negligible: 0.004 and 0.002 percentage points, respectively.

Telecommunications investment has been much higher during the observation period. In 1983, the nominal capital investment in telecommunications was FIM 1.5 billion which was slightly lower than hardware investment. In 1995, nominal telecommunications investment amounted to FIM 3.6 billion. The growth rate in telecommunications capital investment has been considerably lower than in hardware (ITU World Telecommunications Indicator 1996).

We constructed telecommunications capital stock for 1983-95 from the ITU investment series. The capital expenditure series for physical capital has been deflated by the producer price index of Statistics Finland. Subsequently, net capital stock was formed with the perpetual inventory method utilizing a depreciation rates of 10 per cent.

During 1983-95, the average growth rate of real telecommunications capital investment was five per cent annually in Finland. In 1995, the size of telecommunications net capital stock was about one fourth of hardware net capital stock. Average net income share for the telecommunications capital stock was around 0.01 per cent or approximately the same as that of the computer hardware stock. After scaling the income shares to unity, the contribution of telecommunications investment to net output growth turned out to be on average 0.03 percentage points per annum during the observation period. This is about equal to the contribution of software capital stock. If we use a depreciation rate of 25 per cent to form the capital stock, the contribution of telecommunications capital stock to net output growth is halved.

It is possible to find still other components that would fall in the broad category of information technology. However, this would not decrease the contribution of multifactor productivity since we would only divide the total physical capital stock into an increasing number of components – only some of the contribution of other physical capital would be transferred to information technology.

5. ASSUMPTIONS OF THE NEOCLASSICAL MODEL REVISED

Standard neoclassical assumptions underlying the growth accounting framework may understate the actual contribution made by information technology. In this section, we discuss the three neoclassical assumptions and show how they affect the results presented in the previous section.

The first neoclassical assumption requires constant returns to scale in production. This implies that the sum of income shares equals unity. In the extended model with total information technology, it is possible to scale the income shares of capital and labour to unity as usual and then add information technology income shares to the framework without forcing the shares to equal unity again.

The effect of easing the first assumption this way does not have a major effect on the results. On average, the sum of income shares without scaling information technology has been 1.020 in 1983-96 in gross growth and

1.007 in net growth accounting. Hence, scaling has a negligible effect on contributions. The size of the information technology input is too small to change the results even if the assumption of constant returns to scale is relaxed.

The second and third assumptions provide us with more interesting possibilities. In particular, computers may yield supernormal returns or generate positive externalities. If this is the case, the neoclassical growth accounting would misallocate a part of the contribution from information technology to the multifactor productivity residual. This misallocation would result from a falsely specified rental rate. Oliner and Sichel (1994: 288, footnote) argue that the measurement of hardware and software capital stock is not a problem for information technology: most if not all of the disembodied technological change is captured by the quality adjusted prices.

The assumptions concerning the absence of externalities and competitive equilibrium have been widely examined in the literature. On the basis of arguments presented in recent studies, we can adjust the results of the previous section.

Romer (1987) has argued that an increase in a firm's physical capital raises the level of technology available also to other firms. Due to knowledge spillovers resulting from positive externalities, the coefficient of capital should, in Romer's opinion, range from 0.7 to 1.0 instead of the usual income share of 0.3. According to this argument, externalities produce higher social return on capital than private return. Another paper leading to the same conclusion is by De Long and Summers (1991). They argue that employees learn new skills and more efficient production methods after the installation of new equipment. This knowledge is assumed to create positive externalities for other firms as well.

In Finland the income share of capital is around 0.4. We examine the Romer argument by equalizing the income share to unity. Technically, the net rental rate i is replaced by net social return i_{soc} which is obtained by multiplying i by 2.53 (=1.0/0.395) or 3.62 (=1.0/0.276) for gross and net growth accounting, respectively. This yields the adjusted income shares for IT. Increasing returns to scale exist when the sum of income shares is not restricted to unity. The results for the whole period are presented in Table 5.

Compared to baseline results, the Romer case yields higher estimates for IT especially in net growth accounting. The contribution from other physical capital more than doubles due to the bigger income share. The share of multifactor productivity drops to 66 per cent in gross output growth and 77 per cent in net output growth. Therefore, approximately one third of the multifactor productivity in the baseline results can be explained by externalities, once Romer's argument is introduced.

TABLE 5
CONTRIBUTIONS TO GROWTH OF REAL OUTPUT 1983-96, ALTERNATIVE SCENARIOS

		Romer case		Brynjolfsson and Hitt case	
		GROSS	NET	GROSS	NET
output growth[1]		2.38	2.36	2.38	2.36
contributions[2]	total IT	0.68	0.58	1.04	0.86
	hardware	0.55	0.47	0.85	0.70
	software	0.11	0.09	0.17	0.14
	comp.labour	0.02	0.03	0.02	0.03
	K	0.85	0.85	0.32	0.26
	L	-0.73	-0.90	-0.69	-0.85
	MFP	1.58	1.82	1.71	2.09
income shares[1]	hardware	2.5	2.1	3.8	3.1
	software	0.4	0.4	0.6	0.5
	comp.labour	1.1	1.2	1.0	1.2
	K	97.5	98.0	36.9	26.6
	L	60.3	71.1	57.7	68.5
growth rates[1]	hardware	24.7	24.7	24.7	24.7
	software	32.0	32.0	32.0	32.0
	comp.labour	2.3	2.3	2.3	2.3
	K	0.9	0.9	0.9	0.9
	L	-0.9	-0.9	-0.9	-0.9

[1] per cent

[2] percentage points

Even if information technology does not generate sizeable positive externalities, it is possible that the second neoclassical assumption is violated. Computers may earn a higher private rate of return than other physical capital. At the firm level, this view has been presented by Brynjolfsson and Hitt (1996). Their study was based on 367 large firms in the USA in 1987-91. The gross return on computer investment was estimated to be 81 per cent. After subtracting the $(\delta - \dot{p}_c)$ term, this translates to a net rental rate *i* of 56 per cent.

The third and fourth columns of Table 5 present the results based on Brynjolfsson and Hitt's estimate of net rental rate. The remarkably high return on IT investment attributes most of the output growth to computers. In this extreme case, nearly one-third of the total factor productivity is distributed to IT input. It should be noted that Brynjolfsson and Hitt's estimate may be biased upwards since software was not included in their regressions. If the true cost of IT capital stock is higher, marginal productivity will fall accordingly. As Brynjolfsson and Hitt (1995: 555) point out, the findings do not necessarily apply to a broader definition of IT. In Table 5, this is assumed by applying the higher rate of return to software as well.

Krueger (1993) argued that computers increase labour productivity at the firm level. He found that workers using computers earn a substantial nominal wage premium which is interpreted to stem from improved productivity. If the contribution of a wage premium to an increase in real wages reflects an equivalent change in labour productivity, we can directly estimate the effect of the greater use of computers on gross output.

Earlier we controlled for the increased educational level in the labour input. However, accounting only for the formal education can underestimate the quality improvement in labour input. Specifically, employees can learn new skills and better methods after computers have been provided for them. This increases labour productivity in all educational levels.

In French panel data, Greenan and Mairesse (1996) reported an increase of 18 per cent in average real wage for computer-literate employees in 1987. Asplund (1997) estimated that the wage premium from using computers at work was around 8 per cent in Finland at the end of the 1980s. In addition, she reported that the share of employees using computers at work had increased 23.4 percentage points; from 33 per cent in 1987 to 56.4 per cent in 1993.[2]

[2] The analysis was based on four cross-sections from the Labour Force Survey by Statistics Finland (Asplund 1997: 2-4).

From Asplund's results, it can be estimated that computers have contributed about 1.9 percentage points (0.08 multiplied by 0.234) to the average wage over the 1987-93 period. Thus, the contribution is 0.31 percentage points a year. In competitive equilibrium, the rise in the average real wage corresponds to an equivalent increase in labour productivity.

In order to complete the exercise, we assume that the productivity increase was channelled entirely to output growth without reductions in employment. To sum up, the use of computers promoted gross output growth by 0.31 percentage points annually in 1987-93. As can be seen in Table 3, this is less than the contribution from information technology. Hence, the increased labour productivity reflected by wage premiums on computer use does not increase the earlier estimates. The results do not underestimate the impact of IT even if we control for the productivity increase at the firm and employee level.

6. SUMMARY

In this paper, we have examined the role of information technology in economic growth in the Finnish economy. During the period 1983-96, the average annual contribution from computer hardware, software and labour on real output growth in the nonresidential business sector was estimated. In addition, results for two subperiods of the 1980s and the 1990s were computed.

In the whole period, computer hardware accounted for 0.1 percentage points of the average annual net growth of 2.4 per cent. The contribution is half of that of other fixed capital, even though computer hardware represents only 2.5 per cent of the total net capital stock. The sharp decline in employment affects the results which can be seen from the high proportion of multifactor productivity in output growth. The contribution of the MFP even exceeds net output growth in offsetting the negative impact of labour input.

Once the definition of information technology is broadened to include software and computer labour, the contribution of computer services grows by approximately one third from that of the hardware only. The share of information technology in net growth grows from 6 per cent to 8 per cent when software and computer labour are included. Since the depreciation of computer capital stock is quite high, the contribution of information technology on gross output growth is higher. Around 16 and 20 per cent of the gross output growth in 1983-96 can be attributed to hardware and total information technology, respectively. These contributions are slightly higher than those reported by Oliner and Sichel (1994: 285,303). Over the period of 1987-93, they found the contributions of hardware and information technology to be 8 and 16 per cent, respectively, to gross output growth in the US data.

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ELECTRIC DATA SOURCES

Association of Finnish Local and Regional Authorities (Suomen Kuntaliitto)	(www.kuntaliitto.fi/tietot/tila.htm)
Bureau of Labour Statistics	(www.bls.gov/sahome.html)
European Information Technology Observatory	EITO 97 CD-ROM
International Telecommunication Union / OECD	ITU World Telecommunications Indicator 1996 (stars2.exe)
Ministry of Finance	(www.vn.fi/vm/suomi/muuta/vhtt/ vm96.pdf)
OECD Economic Outlook	available through ETLA (www.etla.fi)
Research Institute for Finnish Economy (ETLA) Database	(www.etla.fi)

APPENDIX I

The average monthly salaries for employees by sector and education are taken from Wages and Salaries publications of Statistics Finland. These are published for the private sector from 1990 onward. In 1992, salary statistics included 1.3 million employees, covering 60.5 per cent of the work force in the private sector (Wages and Salaries 1992/93: 7). The average earnings are given for five different sectors: central government, local sector, welfare services, industry and services. In addition, the number of employees in each educational level is given for each sector. The average earnings by educational levels in the private sector can be calculated from the data on industry and services.

Other sources of information needed to construct the labour quality index are the Education and Professions of Labour Force publications (Työvoiman koulutus ja ammatit 1984-92/93 and 1986-95). They include data on labour force by employer sector and educational level. Sectors are private and public sector. The educational breakdown is based on Labour Force Survey which is conducted by interviewing a random sample of 12 000 people monthly. Annual figures are calculated as averages of the monthly figures. In 1992, there were around 1.7 million employees in Finland according to Labour Force Survey (Wages and Salaries 1992/93: 7).

In salary statistics, employees are divided into eight educational levels whereas there are five levels in the Labour Force Survey. Fortunately, it is straightforward to reduce the classification used in salary statistics to a five-level scale: primary education (9 years at most), lower secondary education (10-11 years), upper secondary education (12 years), higher education - lower level (13-15 years, up to BA level) and higher education – higher level (16 years or more, MA level and higher).

In 1990-94, the average of annual wage premiums earned by employees in different educational levels is calculated with respect to primary education. Denoting primary level by 100, the wage premiums are presented in Table A1. Table A1 also includes wage premiums from two other studies: Asplund(1997) is based on a regression model with the data from 1987, 1989, 1991 and 1993 Labour Force Surveys. In Table A1, results from the first year are repeated. Tiainen(1994) reports wage premiums in a public sector survey in 1983. On the whole, the premiums given by salary statistics and the two studies are similar to each other for the first three educational levels. The difference at the high education level probably results from the fact that wage premiums are smaller in the public sector, a fact that is not included in our calculations. The dispersion of wages may also have widened since the 1980s.

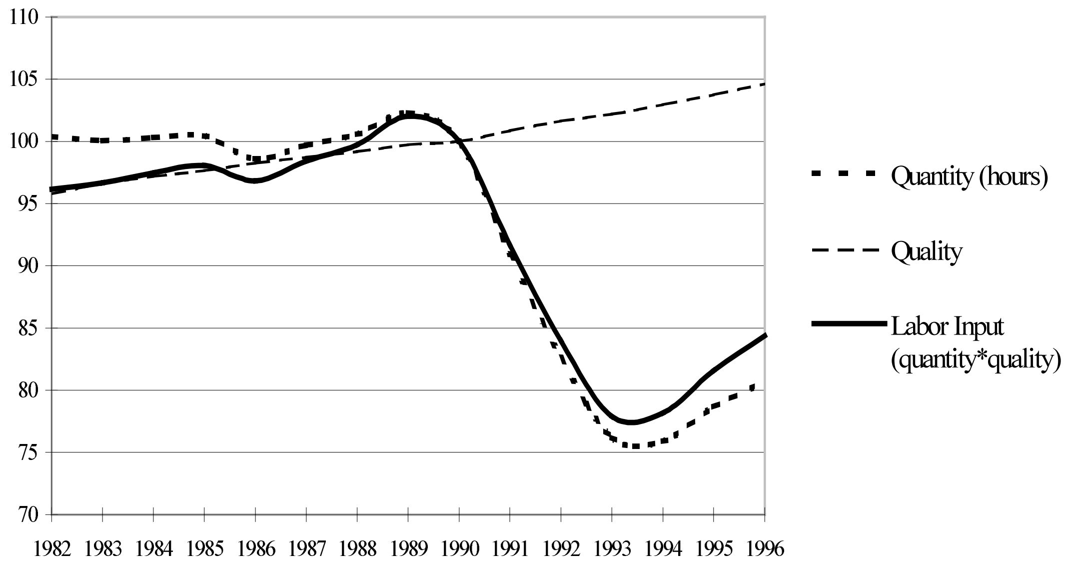
TABLE A1
WAGE PREMIUMS BY EDUCATIONAL LEVEL

Educational level	Salary statistics (private sector)	Asplund (1997)[1]	Tiainen (1994)[1]
Primary education	100	100	100
Lower secondary	105.9	105.7	103.6
Higher secondary	123.8	120.4	118.6
Higher education-lower level	164.6	143.3	139.6
Higher education-higher level	203.0	160.9	189.9

[1] classes have been combined.

The percentage shares of each educational class in private sector employees are available from 1984 to 1995. Multiplying these shares by the wage premiums presented above we get a quality index for labor. Years 1983 and 1996 for the quality adjusted labor input index are extrapolated using the nearest two years. Figure A1 shows that the quality as measured by the educational level of employees has risen during the observation period, offsetting the decrease in hours worked.

FIGURE A1
QUALITY ADJUSTED INDEX FOR LABOUR INPUT (1990 = 100)



APPENDIX II

TABLE A2
SUMMARY RESULTS FROM COMPUTATIONS
WITH NON-HEDONIC PRICE INDEX

	Basic model				Model with computer hardware			
	gross output growth	K	L	MFP	hardware	K	L	MFP
1983-96	2.38	0.40	-0.73	2.71	0.21	0.39	-0.73	2.50
1983-90	4.01	1.19	0.29	2.54	0.29	1.15	0.29	2.29
1991-96	0.47	-0.51	-1.93	2.90	0.13	-0.49	-1.91	2.74
	net output growth	K	L	MFP	hardware	K	L	MFP
1983-96	2.36	0.31	-0.91	2.96	0.07	0.31	-0.90	2.87
1983-90	4.06	0.87	0.34	2.85	0.10	0.86	0.34	2.76
1991-96	0.39	-0.33	-2.37	3.09	0.04	-0.33	-2.35	3.02

	Model with information technology							
	gross output growth	Total IT	hardware	software	computer labour	K	L	MFP
1983-96	2.38	0.28	0.21	0.05	0.02	0.39	-0.71	2.41
1983-90	4.01	0.37	0.28	0.04	0.04	1.15	0.28	2.22
1991-96	0.47	0.18	0.13	0.06	0.00	-0.48	-1.87	2.64
	net output growth	Total IT	hardware	software	computer labour	K	L	MFP
1983-96	2.36	0.11	0.07	0.02	0.03	0.31	-0.89	2.82
1983-90	4.06	0.16	0.09	0.01	0.05	0.86	0.33	2.71
1991-96	0.39	0.06	0.04	0.02	0.00	-0.33	-2.31	2.96

The nominal investment series for computer hardware and software have been deflated with wholesale price index for office and computing equipment. Compiled by Statistics Finland, this index has not been adjusted for quality changes (see Figure 3). As before, the unit in output growth rates is one per cent and the contributions are in percentage points.

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