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THE PRODUCTION AND USE OF ICT IN FINLAND, 1975–2001**

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ABSTRACT: This paper presents new calculations for the production and use of information and communications technology (ICT) in Finland from 1975 to 2001. ICT-production has in the late 1990s had significant impacts on growth and labour productivity (LP). As the increase in LP seems to have mushroomed only in the production of ICT, aggregate LP growth experienced a slowdown. Labour productivity growth in the period 1995 to 2001 manifests larger structural changes than in previous periods, with the step-up in multi-factor productivity being the most notable. The relative contribution of ICT-capital deepening has also increased. To put the Finnish productivity and growth into perspective, we also report recent evidence from other advanced countries.

KEYWORDS: information and communication technology, ICT, new economy, labour productivity, structural change, multi-factor productivity, MFP, growth accounting.

JEL CODES: O3, O4, O5.

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1. INTRODUCTION

Pohjola (2002) defines the New Economy as the globalization of business and the revolution in *information and communication technology* (ICT). He points out that the emergence of new markets, trade and capital deregulation combined with the rapid technical advancements and sharp price declines in information and communications technology truly reflect something new in the economy.

Finland has also very recently undergone major structural changes. Finland was still in 1945 a backward agrarian country with a share of primary production to GDP more than forty per cent. However, due to rapid post-war productivity growth Finland caught-up with the technology frontier, and transformed in the 1990s to a modern high-tech country with a manufacturing industry on a par with the United States (Jalava, Heikkinen & Hjerppe, 2002). Furthermore, having been one of the advanced countries least specialized in ICT in the early 1990s Finland is presently among the most ICT-intensive countries in the world (Koski, Rouvinen & Ylä-Anttila, 2002). In this transformation process the production of ICT has played a major role, with the roles of Nokia and the ICT cluster being crucial (Ali-Yrkkö 2001, Paija 2001, and Daveri & Silva, 2002). Indeed, Nokia singlehandedly – according to Ali-Yrkkö & Hermans (2002) – accounted for 30 per cent of GDP growth in the year 2000.

The objective of this paper is to quantify the impact of both ICT-production, which is the Finnish success story of the 1990s, and ICT-use on the Finnish non-residential market sector, updating and extending the analysis of Jalava & Pohjola (2002).

To ascertain the impact of structural change on *labour productivity* (LP) growth a shift-share analysis in the tradition of van Ark (2001) and Lee & Pilat (2001) is performed. That is, we will examine whether a shift of labour to industries with either a higher level or higher rate of growth of LP has taken place. In van Ark's (2001) results on 10 advanced countries, an increase in the shift components was observed in all surveyed countries (except Finland) from the early 1990s to the late 1990s. In our results Finnish labour productivity growth in the period 1995 to 2001 manifests larger structural changes than in previous periods, with the step-up in multi-factor productivity being the most notable.

Previous studies on the growth contribution of ICT capital services to Finnish economic growth include Colecchia & Schreyer (2002) and Daveri (2001). Colecchia & Schreyer (2002) have, using the same age-efficiency profiles for all countries, calculated the contribution of capital services to the economic growth of certain advanced countries. In all nine OECD countries surveyed, the absolute contribution of ICT has increased in the late 1990s. In Finland they found ICT-capital services to contribute 0.6 percentage points of growth in 1995-99 (in the same time period Jalava & Pohjola, 2002, found the contribution to be 0.7 percentage points). Colecchia & Schreyer (2002) conclude in their paper that the diffusion and usage of ICT plays a key role, and that the existence of a large ICT-producing sector is not necessarily a prerequisite for positive benefits on output growth. Daveri (2001) is a growth accounting study for the EU countries (less Luxembourg) and the United States. He finds that in the period 1991 to 1999 ICT capital services contributed between 9 and 32 per cent to GDP growth. Ireland had the lowest contribution. Austria, Denmark, Greece and Spain had a contribution between 15 and 20 per cent, and the contributions in the rest of the countries were above 20 (in Finland 21) per cent, the highest contributions being in Germany (30 per cent) and Sweden (32 per cent). When the combined contributions of ICT capital services and *multi-factor productivity* (MFP) to

GDP growth are looked at, Sweden and Germany have the second and third highest contributions (98 and 80 per cent respectively). The country with the highest combined contribution of ICT capital and MFP is, according to Daveri (2001), Finland with 155 per cent (this high number is explained by the fact that the contributions of other capital and labour are negative).

We also observe that the Finnish growth picture differs from the U.S. one (Jorgenson, Ho & Stiroh, 2002), although there are some similarities. Both countries experienced a step-up in economic growth in the late 90s, with major contributions from labour and ICT-capital services. However, the contributions of non-ICT capital and MFP differ markedly. In Finland the impact of non-ICT capital services to growth in the late 1990s is virtually non-existent, whereas in the US its impact is important. And though both countries experienced an increase in MFP growth, the US growth picture is not as much relying on MFP as the Finnish one.

This paper is organized as follows: *Section 2* presents the production function used and *Section 3* shows the impact of the production of ICT on the Finnish non-residential market sector; in *Section 4* labour productivity growth as well as the impacts of structural change on labour productivity is reported; *Section 5* shows the empirical results of the growth accounting exercise and *Section 6* concludes.

2. THE PRODUCTION FUNCTION

We use standard neoclassical growth accounting in the tradition of Solow (1957), Jorgenson & Griliches (1967) and Jorgenson & Stiroh (2000) to decompose both the economic growth and labour productivity growth of the non-residential market sector. Aggregate gross value added can be expressed as:

$$Y(Y_{ICT,t}, Y_{O,t}) = A_t F(K_{ICT,t}, K_{O,t}, L_t), \tag{1}$$

where at any given time *t*, aggregate value added *Y* is assumed to consist of the production of ICT goods and services Y_{ICT} as well as of other production Y_O. These outputs are produced from aggregate inputs consisting of ICT capital services K_{ICT}, other capital services K_O and labour services *L*. The level of technology or MFP is here represented in the Hicks neutral or output augmenting form by parameter *A*. Assuming that constant returns to scale prevail in production and that product and factor markets are competitive, growth accounting gives the share weighted growth of outputs as the sum of share weighted inputs and growth in multi-factor productivity:

$$\hat{Y} = w_{ICT}\hat{Y}_{ICT} + w_O\hat{Y}_O = v_{ICT}\hat{K}_{ICT} + v_O\hat{K}_O + v_L\hat{L} + \hat{A}, \tag{2}$$

where the hat symbol denotes change, *w* is the nominal output share and *v* is the nominal income share. Equation 2 can be rearranged to:

$$\hat{Y} - \hat{H} = v_{ICT}(\hat{K}_{ICT} - \hat{H}) + v_O(\hat{K}_O - \hat{H}) + v_L(\hat{L} - \hat{H}) + \hat{A} \tag{3}$$

where *H* is hours worked. Thus the change in labour productivity is due to ICT and other capital deepening as well as changes in labour quality and MFP.

3. THE PRODUCTION OF ICT

The production of ICT has been the success story of recent Finnish economic history. Whereas non-residential market production has grown nearly seven-fold from 1975 to 2001, ICT-production[1] has grown 28-fold. Indeed, in 2001 the share of the ICT-producing industries in the gross value added of the market sector is already 15 per cent (Table 1). As the prices have risen more slowly in ICT-production (on average 3.0 per cent in 1975–2001), than in the non-residential market sector (on average 4.5 per cent in the same period), the nominal shares are not even higher though the volume growth of the industries producing ICT has been quite impressive, an annual average of 9.9 per cent 1975–2001, compared with market production's 2.9 per cent. In the period 1995–2001 the volume growth of ICT production increased to an astonishing 20.3 per cent annual average and by far exceeding the corresponding 5.5 per cent annual growth of the market sector. Thus the contribution of ICT-producing industries to the volume growth of the non-residential market sector experienced a significant step-up in the late 1990s (Table 2).[2] One feature accompanying the very rapid volume growth of the ICT-producing industries in the late 1990s is their rapid price declines. In fact, the ICT-producing industries experienced an average annual price decline of 1.0 per cent 1995-2001, whereas the non-residential market sector's prices increased by 1.3 per cent annually (which is a significant slowdown compared to the 1975-2001 average).

Table 1: Shares of ICT industries in the value added of the non-residential market sector.

(per cent)	1975	1980	1985	1990	1995	2001*
Manufacture of electrical and optical equipment:	*2.1*	*2.0*	*2.6*	*2.9*	*4.8*	*9.3*
Office machinery and computers (ISIC 30)	0.1	0.1	0.3	0.4	0.3	0.0
Electrical machinery (ISIC 31)	1.2	1.2	1.1	1.0	1.2	1.1
Radio, TV and communication equipment (ISIC 32)	0.5	0.4	0.8	1.0	2.7	7.4
Medical and precision products(ISIC 33)	0.3	0.3	0.4	0.5	0.7	0.8
Telecommunications services (ISIC 642)	*1.2*	*1.6*	*1.8*	*1.7*	*1.9*	*3.5*
Computer software and services (ISIC 72)	*0.4*	*0.6*	*0.9*	*1.2*	*1.3*	*2.4*
Total ICT	***3.7***	***4.2***	***5.3***	***5.8***	***8.0***	***15.3***

Calculations based on data from Statistics Finland's National Accounts Database.

Table 2: Output contribution of ICT production in the non-residential market sector.

(per cent)	1975-1990	1990-1995	1995-2001*
Output growth, per cent	3.2	-0.7	5.5
Contribution from ICT industries, percentage points	0.3	0.5	2.0

Calculations based on data from Statistics Finland's National Accounts Database.

4. LABOUR PRODUCTIVITY AND STRUCTURAL CHANGE

Especially in the latter half of the 1990s labour productivity growth in the ICT-producing industries has been very rapid. As a consequence, the level of LP in these industries is twice as high as in the non-residential market sector on average (Tables 3 and 4). In 1975 the labour productivity level of ICT-using[3] industries was the highest, but this lead slowly evaporated. The growth profile of the ICT-users differs from the ICT-producers and the other industries, since during the recession labour productivity growth experienced a major slowdown in ICT-using industries (1.7 per cent on an annual average). In contrast the growth in labour productivity in ICT-producing industries and other industries accelerated during the recession to 7.2 and 4.2 per cent respectively. However, in 1995-2001 the growth rate literally exploded in the production of ICT, whereas ICT-using industries regained only 0.1 percentage points of their pre-recession growth rate and the other industries slumped to an all-time low.

Table 3: Average annual growth of labour productivity in non-residential market sector.

(per cent)	1975-1990	1990-1995	1995-2001*
ICT-producers	4.6	7.2	10.3
ICT-users	3.3	1.7	1.8
Other	3.4	4.2	2.0
Total	3.7	4.0	3.4

Calculations based on data from Statistics Finland's National Accounts Database.

Table 4: The levels[4] of labour productivity in the non-residential market sector.

(index)	1975	1980	1985	1990	1995	2001 *
ICT-producers	135	133	141	146	146	195
ICT-users	143	149	148	139	144	137
Other	91	89	87	87	84	79
Total	100	100	100	100	100	100

Calculations based on data from Statistics Finland's National Accounts Database.

To ascertain the impact of structural change on labour productivity growth a shift-share analysis in the tradition of van Ark (2001) and Lee & Pilat (2001) is performed. The relative change in labour productivity can be expressed as:

$$\frac{LP_t - LP_{t-1}}{LP_{t-1}} = \frac{\sum_{i=1}^{n}\left(LP_{i,t} - LP_{i,t-1}\right)S_{i,t-1} + \sum_{i=1}^{n}\left(S_{i,t} - S_{i,t-1}\right)LP_{i,t-1} + \sum_{i=1}^{n}\left(S_{i,t} - S_{i,t-1}\right)\left(LP_{i,t} - LP_{i,t-1}\right)}{LP_{t-1}}, \quad (4)$$

where *LP* is the level of labour productivity, S_i is industry *i*'s share of all hours worked and *t* is time. The first term on the right side of the equation is the industries' internal (within) productivity effect, i.e., sub-industries impact on aggregate productivity change. The second term on the right is the static shift effect of labour, that is, the contribution of a shift of labour to industries with a higher level of labour productivity. The third term on the right depicts the dynamic shift effect of labour, i.e., the contribution of labour shifting to industries with a higher than average labour productivity growth rate.

The results of the shift-share analysis can be seen in Table 5. During the early 90s recession labour input was drastically diminished (in 1990 the amount of hours worked was 3,335.2 million and in 1994 only 2,574.3 million, i.e., it shrunk to 77 % of the pre-recession level). As expected, the within effect is the most significant factor explaining labour productivity growth in the non-residential market sector. The contribution of the within effect has in the late 90s diminished in favour of the static and dynamic shift effects. The contribution of the dynamic shift was near zero until 1995-2001 when it increased to 2 per cent. The impact of the static shift effect increased significantly in the late 90s to more than 12 per cent. Interestingly the manufacture of electrical and optical equipment alone in 1995-2001 contributed as much as 30.8 percentage points of the within effect, as well as 9.3 and 1.3 percentage points of the static and dynamic shifts respectively.

In van Ark's (2001) results for Finland a similar increase in the dynamic shift effect to 2 per cent was also to be seen (from 1990-95 to 1995-99), however, since the contribution of the within effect stayed at approximately 94 per cent, differing from our results he did not observe a major increase in the static shift effect, but rather that the increase in the dynamic shift's contribution came at the expense of the static shift. As van Ark's (2001) calculations are for the whole economy, i.e., including the public and non-profit sectors (which in the national accounts are compiled with the assumption of no change in labour productivity) and the residential sector (for which there is no labour input in the Finnish national accounts), we find that his results are not that dissimilar from ours. What is interesting is that van Ark (2001) in all 10 advanced countries analyzed (except Finland) found a significant step-up in the pace of structural change in labour productivity from 1990-95 to 1995-99. In fact, he reports that the combined contributions of the static and dynamic shifts was negative in 1990-95 in Canada, Denmark, France, the Netherlands, the UK and the US. Only Finland, Germany, Italy and Japan had a positive structural change during the whole decade.

Table 5: Impact of structural change on LP growth in the non-residential market sector.

	1975-1990	1990-1995	1995-2001*
Within	93.1%	91.4%	85.4%
Static	6.7%	8.5%	12.6%
Dynamic	0.2%	0.1%	2.0%
Total	100.0%	100.0%	100.0%

Calculations based on data from Statistics Finland's National Accounts Database.

5. DECOMPOSING THE GROWTH [5]

Since the within effect was the most significant in explaining labour productivity growth, we use neoclassical growth accounting (equation 3) to decompose the contributions to labour productivity growth. In Table 6a is shown the decompositions of change in labour productivity in the Finnish non-residential market sector, and Table 7a shows the growth decomposition (equation 2). In both tables the figures from 1975-1995 are from Jalava & Pohjola (2002) and the figures for 1995-2001 are updated calculations using an identical methodology[6]. The data is from the National Accounts Database in Statistics Finland, except for the data on hardware and telecommunications expenditure[7] and deflators[8].

Table 6a: Contributions to LP growth in the Finnish non-residential market sector.

	1975-1990	1990-1995	1995-2001*
Growth rate of labour productivity [1]	***3.7***	***3.9***	***3.4***
Contributions from [2]			
ICT capital	*0.3*	*0.6*	*0.6*
Hardware	0.1	0.3	0.4
Software	0.1	0.2	0.1
Communications eq.	0.0	0.1	0.1
Other capital	*1.0*	*0.7*	*-0.9*
Labour quality	*0.2*	*0.2*	*0.2*
Multi-factor productivity	*2.2*	*2.3*	*3.7*

1 per cent. 2 percentage points. Numbers may not add to totals due to rounding and averages.

Sources: Jalava & Pohjola (2002); Calculations based on data from Statistics Finland's National Accounts Database and WITSA.

Table 6b: Contributions to labour productivity growth in the US market sector.

	1973-1995	1995-2000
Growth rate of labour productivity [1]	***1.4***	***2.4***
Contributions from [2]		
ICT capital	*0.3*	*0.8*
Other capital	*0.6*	*0.6*
Labour quality	*0.2*	*0.2*
Multi-factor productivity	*0.3*	*0.8*

1 per cent. 2 percentage points. Numbers may not add to totals due to rounding and averages.

Source: Jorgenson, Ho & Stiroh (2002).

Contrary to the United States (as reported by Jorgenson, Ho & Stiroh (2002)[9] in Table 6b), there is no pick-up in LP growth in the late 1990s to be seen in Table 6a for Finland[10]. Actually the average annual growth of LP is only 3.4 per cent in the period 1995 to 2001, an all time low. This since LP growth having been 6.4 per cent in 2000 plummets to -0.2 per cent in 2001. The absolute contribution of ICT-capital deepening stays at a level 0.6

percentage points in 1990-95 and 1995-2001. However, the relative contribution of ICT-capital deepening increases from 15 to 18 percentage points. The contribution of labour quality is the same throughout the observation period, and the contribution of non-ICT capital deepening is in the late 90s strongly negative. In the US labour productivity growth relies mainly on capital deepening, whereas in Finland MFP contributes most to LP. Finnish MFP experiences a significant step-up in the late 90s, reaching an average of 3.7 per cent annually. Furthermore, using output shares the ICT-producing industries contribution to MFP growth in 1995-2001 is 0.9 percentage points. Hence a lot of MFP growth is generated in non-ICT-producing industries. Thus our results would seem corroborate Daveri & Silva's (2002) observation that productivity spill-overs from ICT-production to certain ICT-using industries are fairly important.

What then is behind the rapid increase in MFP's growth rate in the late 90s? It would seem - at least judging by the international level of LP comparison for the whole manufacturing sector done by van Ark & Timmer (2001) - that until the 1990s a technological catching-up process was taking place in Finland. This changed in the 90s to Finnish ICT manufacturing being at the world's technology frontier. Thus the very favourable MFP figures can be seen as the result of the improvements in corporate governance, organization and logistics taking place (see Häikiö, 2002, on the story of Nokia's evolution to a global player), as well as the results of technical improvements. Indeed, the number of valid patents recognised by the National Board of Patents and Registration of Finland jumped from a bit under 8,000 in 1975 to more than 19,000 in 2000. Also the share of research & development (R&D) of GDP in Finland was as much as 3.3 per cent in 2000 (the business sectors share was 71 per cent of total R&D). This high R&D to GDP ratio was at the close of the 20th century second only to Sweden (3.8 per cent in 1999).

Table 7a presents the growth decomposition, the income shares and the growth rates for Finland. ICT-capital's growth contribution increases significantly from 1990-95 to 1995-2001 (0.3 to 0.8 percentage points). This notwithstanding the fact that the growth in the non-residential market sector's gross value added having grown in 2000 by 8.6 per cent only grew by 0.2 per cent in 2001 as the global economic slump also came to Finland. The growth contribution of non-ICT capital is less negative in the late 90s as it was in the early 90s (-0.1 per cent versus -0.7 per cent), and the contribution of labour quantity in 1995-2001 is positive for the first time during the whole observation period. Notable is also the shift in the functional income distribution (the division of nominal value added into the shares of labour and capital), which quite markedly shows an increase in capital's income share. Comparing with the US growth picture (Table 7b) many similarities are to be seen. The growth rate picked up also in the US in the late 90s. The extensive contribution of ICT-capital services and labour services has increased in both countries. However, as was the case with LP the contributions of other capital and MFP differ markedly. In Finland the impact of non-ICT capital services is virtually non-existent, whereas in the US its impact is important. And though both countries experienced an increase in MFP growth, the US growth picture is not nearly as intensive (relying on MFP) as the Finnish one.

Table 7a: Contributions to growth in Finnish non-residential market sector.

		1975-1990	1990-1995	1995-2001*
Output growth [1]		3.2	-0.7	5.5
Contributions from [2]	ICT capital	0.2	0.3	0.8
	Hardware	0.1	0.2	0.5
	Software	0.1	0.1	0.2
	Communications eq.	0.0	0.1	0.1
	Other capital	0.8	-0.7	-0.1
	Labour hours	-0.4	-2.9	1.1
	Labour quality	0.2	0.2	0.2
	Multi-factor productivity	2.2	2.3	3.7
Income shares [1]	ICT capital	1.7	5.0	6.3
	Hardware	0.5	1.5	2.1
	Software	0.6	2.4	2.5
	Communications eq.	0.5	1.1	1.7
	Other capital	33.9	33.8	38.7
	Labour	64.4	61.3	55.1
Growth rates [1]	ICT capital	16.5	7.2	12.9
	Hardware	29.7	15.1	25.9
	Software	12.9	2.7	6.7
	Communications eq.	9.9	9.1	9.3
	Other capital	2.8	-2.1	-0.4
	Labour hours	-0.7	-4.5	2.1

[1] per cent. [2] percentage points. Numbers may not add to totals due to rounding and averages.

Sources: Jalava & Pohjola (2002); Calculations based on data from Statistics Finland's National Accounts Database and WITSA.

Table 7b: Contributions to growth in US market sector.

		1973-1995	1995-2000
Output growth [1]		3.0	4.6
Contributions from [2]	ICT capital	0.4	0.9
	Hardware	0.2	0.5
	Software	0.1	0.3
	Communications eq.	0.1	0.1
	Other capital	1.2	1.5
	Labour hours	0.9	1.3
	Labour quality	0.2	0.2
	Multi-factor productivity	0.3	0.8

[1]per cent. [2]percentage points. Numbers may not add to totals due to rounding and averages.

Source: Jorgenson, Ho & Stiroh (2002).

6. CONCLUSION

The objective of this paper was to quantify the impact of ICT-production and ICT-use on the Finnish non-residential market sector in Finland from 1975 to 2001. ICT-production has in the late 90s had significant impacts on growth and labour productivity (LP). Since the increase in LP seems to have mushroomed only in the production of ICT, aggregate LP growth experienced a slowdown. As in the other advanced countries analyzed by van Ark (2001) the pace of structural change in LP growth has picked-up in the period 1995 to 2001 in Finland. When decomposing LP growth we found, that the relative contribution of ICT-capital deepening has increased but that the step-up in multi-factor productivity contributed the most in 1995-2001. Contrary to the leading New Economy, the United States, there is no pick-up in Finnish LP growth in the latter half of the 1990s to be detected in Finland, quite the opposite. Therefore the sustainability of ICT's positive impact on the Finnish economy is yet to be seen. On a positive note though, Finnish LP growth relies mainly on MFP and not on the extensive capital deepening (which requires massive investments to be sustained) the US does.

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APPENDIX 1

This appendix shows what Tables 3, 4 and 5 look like when industry Manufacture of pulp, paper and paper products (ISIC21) is excluded from the ICT-using industries and included in the non ICT-producing and non ICT-using industries. The slowdown in ICT-using industries LP during the recession (Table A1) is now much more striking than it was in Table 3. The level of labour productivity in ICT-using industries is also lower now, Table A2, than it was in Table 4. The shift-share results differ most with respect to the static shift during the recession (Tables 5 and A3).

Table A1: Average annual growth of labour productivity in non-residential market sector.

(per cent)	1975-1990	1990-1995	1995-2001*
ICT-producers	4.6	7.2	10.3
ICT-users	2.7	0.3	2.0
Other	3.6	4.7	1.9
Total	3.7	4.0	3.4

Calculations based on data from Statistics Finland's National Accounts Database.

Table A2: The levels of labour productivity in the non-residential market sector.

(index)	1975	1980	1985	1990	1995	2001*
ICT-producers	135	133	141	146	146	195
ICT-users	139	139	139	135	125	122
Other	93	92	91	90	91	84
Total	100	100	100	100	100	100

Calculations based on data from Statistics Finland's National Accounts Database.

Table A3: Impact of structural change on LP growth in the non-residential market sector.

	1975-1990	1990-1995	1995-2001*
Within	93.3%	93.6%	85.6%
Static	6.6%	6.5%	12.3%
Dynamic	0.1%	-0.1%	2.1%
Total	100.0%	100.0%	100.0%

Calculations based on data from Statistics Finland's National Accounts Database.

APPENDIX 2

This appendix explains how capital and labour inputs are defined and measured in the analysis carried out in the paper. Gross capital stock (*GS*) is the value of the capital used in production, valued at 'as new' prices, i.e. regardless of age or condition. Thus, the decline in the efficiency of fixed assets is not taken into account when calculating gross capital stocks. *GS* consists of the accumulated value of past investment less accumulated retirements of fixed assets. In Finland, retirements are assumed to follow a skewed Weibull distribution. Thus, the survival function of the share of year *T*'s investments still in use at the end of year *t*, is assumed to be:

$$w_{t-T} = \exp\left\{ -\left[\frac{\Gamma\left(1+(1/a)\right)}{E} t \right]^{a} \right\}, \tag{A1}$$

where $t = t - T + 0.5$, E is average service life and a is a shape parameter. The subscripts for industry (i) and asset type (j) have been suppressed for notational simplicity. The real gross capital stock at the end of year t is:

$$GS_t = \sum_{T \geq t-J_t+1} w_{t-T} I_T \ , \tag{A2}$$

where $T \geq t-J_t+1$, and I_T is the real gross fixed capital formation of year T. $J_t = max\{1.5\theta_t, 100\}$, meaning that the maximum service life of a capital asset is assumed to be 1.5 times the average service life, but not more than 100 years.

Following Jalava & Pohjola (2002), we use a hyperbolic age-efficiency pattern to construct productive capital stocks. The productive capital stock is defined as

$$K_t = \sum_{T \geq t-J_t+1} h_t w_{t-T} I_T \tag{A3}$$

where $h_t = (E - A)/(E - (B)A)$ is the relative efficiency of a t-year-old asset, E is the average service life, A is the age of the asset and B is a parameter that defines the specific shape of the efficiency decline. This parameter is assumed to be 0.5 for equipment and intangible capital, and 0.75 for structures. The user cost or rental price of capital is defined as the rate of return plus depreciation minus capital gain/loss:

$$r_{ijt} = p_{ij(t-1)} i_{it} + p_{ijt} d_{ijt} - (p_{ijt} - p_{ij(t-1)}) \ . \tag{A4}$$

Here, for industry i and asset type j, r is the rental price, p designates the price index for new capital goods, i is the rate of return and d the rate of depreciation (i.e., real consumption of fixed capital divided by real wealth capital stock), and t denotes time. There are two principal ways of estimating user costs. The opportunity or ex-ante approach uses some exogenous value of the rate of return i, for example the base rate of the central bank. The residual or ex-post approach estimates the internal rate of return i with the help of an accounting identity. Defining capital income to equal nominal value added less labour compensation[11], and given information about depreciation, holding gains and capital stock, the rate of return can be estimated residually as

$$i_t = \frac{capital\_income - \left\{ p_t d_t - \left(p_t - p_{t-1} \right) \right\} S_{t-1}}{p_{t-1} S_{t-1}}, \tag{A5}$$

where *S* is real wealth capital stock and *pS* the nominal wealth capital stock, i.e., the market value of the capital stock. The wealth (or net) capital stock is the market value of the productive capital. It is calculated by subtracting the accumulated depreciation from the accumulated value of past investment. To estimate the rate of return, we use the ex-post approach.

The user costs are used to aggregate the productive capital stocks by asset type. We assume that aggregate capital services are a translog function of the services of individual assets. Thus the aggregate volume index of capital services is:

$$c_{jt} = \frac{K_{jt}}{K_{j(t-1)}} = \prod_i \left(\frac{K_{ijt}}{K_{ij(t-1)}} \right)^{v_{ijt}}, \tag{A6}$$

where the weights ν are defined as

$$v_{ijt} = \left(\frac{r_{ijt} S_{ijt}}{\sum_i r_{ijt} S_{ijt}} + \frac{r_{ij(t-1)} S_{ij(t-1)}}{\sum_i r_{ij(t-1)} S_{ij(t-1)}} \right) / 2 . \tag{A7}$$

Here *c* is the volume index of capital services and *K* and *S* denote the productive and real wealth capital stocks, respectively.

The asset types and average service lives that we use for capital goods are shown in Table A4. With the exception of hardware and communications equipment, they are identical to the ones used by Statistics Finland. Capital goods (except hardware and communications equipment) are also classified by industry which explains the variations in service lives shown in Table A4. Household consumption goods, inventories and land are not included in our definition of capital goods.

Table A4: Capital goods' asset types and average service lives

Asset	Average service life in years
Non-residential buildings	20-50
Civil engineering and other structures	20-70
Transport equipment	7-25
Hardware	7
Communications equipment	15
Other machinery and equipment	5-32
Mineral exploration	10
Computer software	5
Entertainment, literary or artistic originals	10
Improvement of land	30-50

As a measure of labour input we used hours worked adjusted for labour quality. The hours worked are cross-classified by educational level and by the average salary of each educational group. In aggregating the volume index of labour input it is assumed that the aggregate input is a translog function of the quantities of individual labour types:

$$\ln L_t - \ln L_{t-1} = \sum_l \overline{v_l} \left[\ln L_{lt} - \ln L_{l(t-1)} \right], \tag{A8}$$

where the weights are given by the average shares of each labour type in the total value of labour compensation:

$$\overline{v_l} = \frac{1}{2}\left[v_{lt} + v_{l(t-1)}\right] \tag{A9}$$

and

$$v_{lt} = \frac{p_{lt} L_{lt}}{\sum_l p_{lt} L_{lt}}, \tag{A10}$$

with p_l being denoting the wage rate of labour type l. A six-category classification of labour by the level of education is applied. To obtain data on hourly wages by educational groups, we use the longitudinal census file for the years 1975, 1980, 1985, 1990 and 1995 (the intermediate years were interpolated). It contains information on 6.4 million people and their economic activities. For the years 1996-99 (for 2000 and 2001 the same structure as in 1999 is assumed), we use the labour force survey and the wage structure statistics. All data are adjusted to national accounts levels.

ENDNOTES

[1] The ICT-producing industries are, following Jalava & Pohjola (2002), throughout this paper defined as encompassing industries: Manufacture of electrical and optical equipment (ISIC 30, 31, 32, 33), Telecommunications services (ISIC 642) and Computer software and services (ISIC 72).

[2] The Törnqvist index was used in the calculations.

[3] The ICT-using industries are throughout this paper, based on van Ark (2001), defined as encompassing industries: Publishing and printing (ISIC 22), Manufacture of chemicals and chemical products (ISIC 24), Wholesale trade and commission trade (ISIC 51), Post and courier activities (ISIC 641), Financial intermediation and insurance (ISIC 65, 66, 67), Renting of machinery and equipment (ISIC 71), Research and development (ISIC 73) and Other business activities (ISIC 74). Differing from van Ark (2001) we also add to ICT-using industries Manufacture of pulp, paper and paper products (ISIC21) which in Finland has a long tradition of using the most advanced technology available (Lehtoranta, 1994). However, to enable comparison Appendix 1 presents the results where ICT-using industries are defined as van Ark does.

[4] The overall LP level in non-residential market production has been normalized to 100. Here the levels are calculated as cross-sections, i.e., using current price data. This is in contrast with the shift-share calculations where time-series LP levels (in constant prices) are used.

[5] See Appendix 2 for the details on how the capital and labour services have been calculated.

[6] See also Jalava (2002) for more on the construction of quality adjusted capital and labour services series for Finland.

[7] Data on hardware and telecommunications expenditure is from WITSA (2002). Since telecommunication expenditure in the WITSA data includes both investment and services, we follow Jalava & Pohjola (2002) and assume that 30 per cent of the expenditure is investment.

[8] To deflate the ICT investment series, we use the same US indexes as Jalava & Pohjola (2002) for hardware and telecommunication equipment and correct them for the exchange rate changes.

[9] They also exclude the government sector, but include services from consumers' durables and owner-occupied housing in their measure of output.

[10] The 1990s has been an exceptional time for Finland. The recession in the early part of the decade was very severe with an ensuing peak in LP as the economy exited the recession. Furthermore, since Finland is at the world's technology frontier in manufacturing, it is hard to maintain a rapid LP growth.

[11] This is the national accounts compensation of employees to which we added the labour income of the self-employed. This income component is estimated by using the hours worked by the self-employed multiplied by the average salary of employees.

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