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The roles of electricity and ICT in economic growth: Case Finland ☆

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Abstract

A quantitative look is taken at electricity and ICT as the engines of economic growth in Finland which was one of the leading countries in the electrification of mechanical drive in industry and which today is one of the leading information societies. It is shown that ICT's contribution to GDP growth in 1990–2004 was three times as large as electricity's contribution in 1920–1938. The improvement of multi-factor productivity in production accounted for 60% of ICT's contribution but only one third of electricity's. Electricity's growth contribution was smaller but ICT's larger than in the United States.

Keywords: Electricity; ICT; General purpose technology; Growth accounting; Productivity

1. Introduction

Economic theory explains how economic growth is driven by advances in technology, that is, in ideas about how to combine inputs to produce outputs. Economic history teaches that growth is not a smooth process but is subject to episodes of sharp acceleration and deceleration which are associated with the arrival, diffusion and exhaustion of new technologies. Some of these may have very broad effects by transforming both household life and the ways in which firms conduct business. Steam, electricity and information and

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communications technology (ICT) are perhaps the most common examples of such technologies (for a survey, see Jovanovic and Rousseau, 2006).

The empirical literature applying the growth accounting approach usually sees the productivity effects of a new technology as arising through three channels. First, there are significant improvements in multi-factor productivity (MFP) in the industries producing the new technology due to rapid advances in technological knowledge. Second, the industries using the new technology experience positive effects on labor productivity as they increase their capital intensity by investing in new capital goods. Third, the industries using the new technology experience a boost in multi-factor productivity growth as they introduce new modes of operation and continually improve the technology by incremental product and process innovations. Such spillovers may result from the re-organization of production that the new technology makes possible.

Crafts (2002, 2004b) has applied growth accounting in assessing and comparing the overall impacts of steam, electricity and ICT. In his 2004 study on the contribution of steam to British economic growth in the nineteenth century, he found that the output and productivity impacts were modest and long-delayed. Steam contributed very little (0.01–0.02 percentage points per year) to the growth of labor productivity before 1830. The peak impact occurred in the period 1850–70 and amounted to 0.4 percentage points per year. These numbers are much smaller than what we have come to expect on the basis of many recent studies measuring the effects of ICT.

In his 2002 paper, Crafts also studied the impacts of electricity and ICT in the United States over comparable periods of time. The total contribution of electricity to GDP per person growth was about 0.6 percentage points per year in 1899–1929 and one percentage point in 1919–29. MFP spillovers resulting from the reorganization of factory work accounted for most of the impact (0.7%-points) in the latter period. This estimate is based on David's (1990, 1991) and David and Wright's (1999) analyses of the impact of the adoption of the electric unit drive on multi-factor productivity growth in U.S. manufacturing. The shift from steam to electric power reduced the energy required to drive machinery but also, as DuBoff (1964: pp. 143–148) and Devine (1983) have shown, it more importantly permitted substantial improvements in factory design. They increased the flow of production, made working environment better, improved machine control and made plant expansion easier. Consequently, the electricity using industries were able to obtain greater output per unit of capital and labor input.

David and Wright (1999, 2003) have shown that capital productivity increased in U.S. manufacturing in the 1920s and that this increase was directly associated with the diffusions of the electric unit drive which they measured by the capacity of secondary electric motors. Contrary to what one would expect using a simple factor substitution model, the growth of capital productivity was associated with rising labor productivity.

The interesting difference between steam and electricity lies in the growth contribution of MFP spillovers. These seem to have been small for steam but very substantial for electricity. One explanation may be that such spillovers are more difficult to measure for steam than for electricity. Crafts (2004b) did not attempt to identify them but concluded that it is unlikely that they have been significant. This is confirmed by Devine's (1983) study which argues that the shift from steam power to electricity was fundamentally different from the previous transition from water power to steam. Electrification was accompanied with new methods of power transmission and distribution as well as improvements in factory design and machine organization whereas steam power was adopted by manufacturers primarily for reasons of location and seasonal availability and of direct cost benefits.

The overall impacts of steam are not, however, easily measurable in a growth accounting framework and may be underestimated. As Rosenberg and Trajtenberg (2004) have shown, the Corliss steam engine served as a catalyst for the massive relocation of industrial activity into larger urban centers in the United States, thus fueling agglomeration economies, attracting further population and fostering economic growth. These relationships may have been different in Britain, but the link between technology and population growth is not accounted for in growth accounting.

Comparing the growth contributions of electricity with Oliner and Sichel (2000) findings on the impacts of ICT in 1974–2000, Crafts concluded that ICT has had at least as large an impact on economic growth as electricity. ICT's overall contribution to GDP per person growth rose from 0.7 percentage points in 1974–1990 to 1.9 in 1996–2000. The notable difference between electricity and ICT is that the latter has not yet generated any measurable MFP spillovers in the ICT using industries. The growth impact has been achieved through the capital-deepening effect. In principle at least, ICT could generate re-organization effects in offices in the service sector in ways parallel to the experience of the factory.

Edquist and Henrekson (2006) have rightly pointed out, however, that the output and productivity contributions from steam and electricity may be underestimated in comparison to ICT because hedonic prices have been used in measuring the quality of ICT products but not in measuring the quality of either steam engines or electric motors.

With this reservation, the existing cliometric evidence can be said to indicate that the contribution to economic growth of information and communications technology outweighs the contributions of steam and electricity. Crafts analyzed the impacts in those countries where these technologies were discovered: steam in Great Britain and electricity and ICT in the United States. It might be interesting to see if the conclusion holds for countries which are not technology leaders but are followers, i.e. countries which have adopted technologies developed by others.

David and Wright (2003) have shown that the experience of delayed and then accelerated MFP growth associated with electrification was not a uniquely American phenomenon. They found similar patterns for the United Kingdom and Japan in the opening third of the twentieth century. In Britain, the diffusion of electric power lagged behind the U.S. in the beginning of the century but matched it already by the end of the 1930s. In Japan, the age of steam power was historically compressed by the rapid process of factory electrification. The transition to the new power regime was already underway before the mechanization of manufacturing plants had been completed. David and Wright conclude that the follower countries can in fact adopt a well-developed technology from abroad relatively quickly without having to go through the learning processes that had occurred in the pioneering country.

Edquist and Henrekson (2006) have demonstrated that also Sweden adopted electricity swiftly and that labor productivity in manufacturing accelerated in the 1920s. However, they were not able to establish a clear correlation across industries between labor productivity growth and the increased use of electric motors.

This paper demonstrates that the diffusion of electricity was as rapid in Finland as in the United States in the 1920s and 1930s. The contribution to economic growth was however somewhat smaller in Finland (0.52 percentage points per year) than in the United States (0.98 percentage points) over comparable periods of time. The main source of the difference is the multi-factor productivity spillovers associated with the use of electricity. They were large in the United States but not observable in Finland.

We also show that the diffusion of ICT was slower in Finland than in the U.S. in 1975–2005. To assess its contribution to productivity growth, estimates based on non-hedonic and hedonic ICT prices are provided. The first ones make it possible to compare the impacts of ICT with the effects of electricity which are not derived using hedonic prices for electric motors. The second set of estimates allows comparisons between Finland and the United States for which only estimates based on quality-adjusted ICT prices are available.

ICT's contribution to GDP growth in 1990–2004 (1.54 percentage points per year) was three times as large as electricity's contribution in 1920–1938 (0.52 percentage points). These technologies also differ with respect to the relative importance of the sources of growth. The improvement of multi-factor productivity in production accounted for 60% of ICT's contribution but only one third of electricity's. No evidence for spillovers from the use of electricity is found. Interestingly, however, the spillovers arising from the use of ICT are sizeable, amounting to 25% of ICT's total contribution. Overall, ICT's contribution to GDP growth turns out to be higher in Finland than in the United States. The difference arises from the larger contributions of MFP in ICT production and from the spillovers associated with ICT use.

The growth accounting approach to the measurement of the contribution arising from a new technology can be criticized for overestimating the impact (see, e.g. Field, 2006). It attributes to this technology all the contributions arising through the three channels identified above. The social savings approach, pioneered by Fogel (1964), is different in that it does not attribute any portion of the capital deepening effect to the new technology, arguing that it is attributable to saving. The measured growth contributions are therefore smaller when the social savings approach is used. We show that the qualitative conclusions obtained still hold when the social saving approach is used: ICT has contributed more than electricity to Finnish economic growth, and electricity's contribution has been smaller and ICT's larger in Finland than in the United States. We also present a counterfactual analysis of what economic growth in Finland would have been without the success in ICT manufacturing. This is done by studying the steady state of the neo-classical growth model

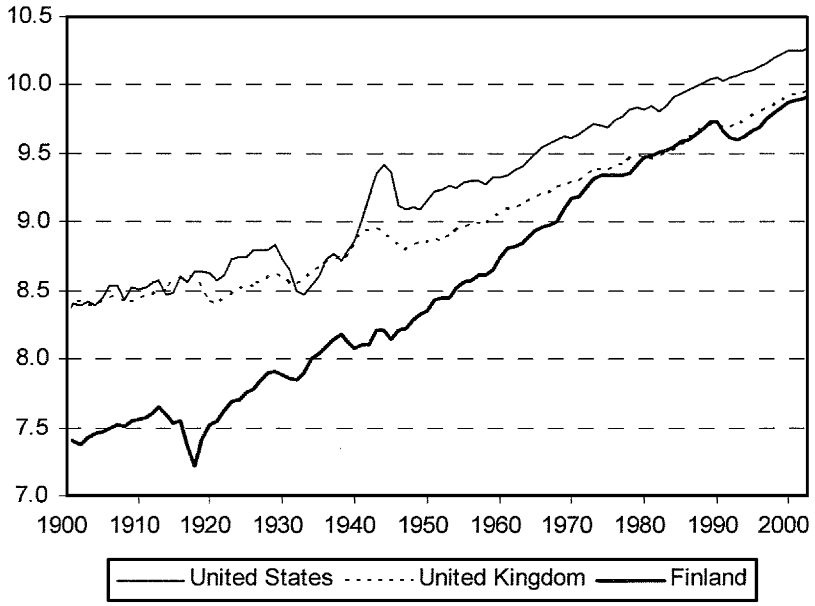

Fig. 1. GDP per capita, 1900–2003 (logarithmic scale, 1990 internatiomal Geary-Khamis dollars). Source: Maddison (2003), revised and updated data available on http://www.ggdc.net/maddison/.

underlying the growth accounting approach. It is shown that the output growth rate would have been about 0.9 percentage points lower.

Before going into the details of the growth accounting results, a brief history of Finnish economic growth is presented in Section 2, and the method for accounting the growth contributions of a new technology is explained in Section 3. Section 6 concludes the paper.

2. Output and labour productivity growth in 1900–2005

The growth rate of real GDP per capita was in Finland among the highest in Western Europe in the twentieth century. According to Maddison's (2003) data, the compound annual growth rate was 2.5% in the period from 1900 to 2003. Given that the growth rate in the United States was 1.9% per year, the Finnish GDP per capita increased from 41% of the U.S. level in 1900 to 71% in 2003. It reached the British level in the 1980s. This rapid convergence is displayed in Fig. 1.

Finland developed from a relatively backward agricultural society to a modern Nordic welfare state during the twentieth century. The advancement in prosperity was initially based on the successful utilization of natural resources by the forest and basic metal industries in the wake of the second industrial revolution. The information and communication technology sector has recently become the leading industry in terms of the contribution to labour productivity and GDP growth. In 2001, labour productivity as measured by value added per hour worked was in Finland higher than in any other EU-15 member country or in the United States in the following four manufacturing industries: pulp and paper, wood and wood products, basic metals, and telecommunications equipment.[1]

The first two rows of Table 1 decompose output growth into the contributions from labor input and labor productivity for the period from 1900 to 2005. Output is measured by the real gross valued added at basic prices and labor input by the number of hours worked. Instead of looking at the total economy, the analysis is confined to the non-residential market sector where the volume of output was 26 times higher at the end of our observation period than at its beginning.[2]

[1] Source: Groningen Growth and Development Centre, ICOP Database 1997 Benchmark, http://www.ggdc.net.

[2] The share of the non-residential market sector in GDP at basic prices stayed rather constant at about 90 per cent in the period from 1900 to 1950. It has subsequently gradually declined to 73 per cent in 2005.

Table 1
Output and labour productivity growth in the Finnish non-residential market sector, 1900–2005

	1900–2005	1900–1913	1920–1938	1952–1973	1973–1990	1990–2005
Labour input	0.3	1.0	1.4	0.0	−0.6	−0.8
Labour productivity	2.8	1.9	3.1	4.5	3.6	3.4
Output	3.1	2.9	4.5	4.5	3.0	2.6

Source. Own calculations, data from Hjerppe (1988), Tiainen (1994) and Statistics Finland.

Over the whole period, 90% of output growth stemmed from increases in labor productivity and 10% from increases in the number of hours worked. Labor's relative contribution was at its highest (about 30%) in the first two sub-periods. It was negative in the last two sub-periods. Following Field's (2003) suggestion, the beginning and endpoints of the periods have here been chosen in such a way that the economy is at similar stages of the business cycle at them. This is done to eliminate the impact of cyclical factors on productivity measures.

As shown in the table, labor productivity growth accelerated from the average rate of 1.9% in 1900–13 to 4.5% in 1952–73. During this period Finland developed from an agricultural into an industrial economy. The trend rate of productive growth has recently been declining but Finland has not suffered from the productivity slowdown to the same extent as many other industrial nations. It will be seen in Section 5 that this is mainly due to its success as an ICT producer.

Fig. 1 reveals that the Finnish economy was hit by a severe depression in the early 1990s. The volume of gross value added fell by 10% between 1990 and 1992 in the non-residential market sector. The recovery was, however, rapid, and the period from 1990 to 2005 does not look very much different from the preceding period in Table 1.

3. Measuring the growth contributions of a new technology

3.1. The growth accounting approach

Growth accounting is a standard method to attribute the observed output growth to increases in the factors of production and to the improvement of multi-factor productivity. The starting point is the production function

$$Y_i(t) = A_i(t)F_i(K_{i,\mathrm{NT}}(t), K_{i,O}(t), L_i(t)). \tag{1}$$

At any given time t, the gross value added Y in industry i is produced from inputs consisting of two types of capital services – new technology capital K_{NT} and other capital K_{O}—and of labor services L. The level of technology or multi-factor productivity is represented in the Hicks neutral or output-augmenting form by parameter A. It shifts the production function.

As explained already by Hulten (1978), growth accounting at the industry level differs from growth accounting at the aggregate level in that the outputs produced by other industries can be used as inputs in any given industry. Therefore, instead of Eq. (1), the industry-level production function should take the form $Q_i = A_i\, F_i(K_{i,NT}, K_{i,O}, L_i, M_i)$ where Q is gross output and M is the quantity of the intermediate inputs used. This formulation would capture the impact on output of efficiency improvement in the production of intermediate inputs. The practical problem in estimating the growth contributions of electricity and ICT in the following two sections of the paper, however, is the fact that separately deflated gross output and intermediate input series are available in the Finnish National Accounts since 2001 only. Therefore, the analysis is here based on value-added production functions.

The basic growth accounting equation gives the growth of output as the sum of the share weighted inputs and the growth in multi-factor productivity

$$\Delta \ln Y_i = v_{i,\mathrm{KNT}}\Delta \ln K_{i,\mathrm{NT}} + v_{i,\mathrm{KO}}\Delta \ln K_{i,O} + v_{i,L}\Delta \ln L_i + \Delta \ln A_i, \tag{2}$$

where the Δ-symbol refers to a first difference, i.e. $\Delta x(t) = x(t) - x(t-1)$, and where the time index t has been suppressed for the economy of exposition. The weights v_{KNT}, v_{KO}, and v_L sum to one and represent the nominal income shares of new technology capital, other capital and labour, respectively, in industry i. All shares are averaged over periods t and $t-1$. The contributions of the inputs to the growth of the aggregate value added are obtained by directly aggregating Eq. (2) over all industries by using their shares in the aggregate value added as the weights:

$$\begin{aligned}\Delta \ln Y &= \sum_i w_i \Delta \ln Y_i \\ &= \sum_i w_i v_{i,\mathrm{KNT}} \Delta \ln K_{i,\mathrm{NT}} + \sum_i w_i v_{i,\mathrm{KO}} \Delta \ln K_{i,O} \\ &\quad + \sum_i w_i v_{i,L} \Delta \ln L_i + \sum_i w_i \Delta \ln A_i.\end{aligned} \tag{3}$$

The weights w_i are again averaged over periods t and $t-1$.

As mentioned in the introduction, in an accounting sense there are three channels through which a new technology can contribute to output growth. The first one is the improvement of multi-factor productivity in the industries producing new technology goods or services. This contribution is included in the last term of Eq. (3). It can be identified by summing the weighted MFP contributions $w_i \Delta \ln A_i$ over those industries that produce new technology products. The second channel is the capital deepening resulting from the use of new technology capital. Its contribution is measured by the first term of the right-hand side of Eq. (3).

In standard neoclassical growth theory, these two are the only channels through which advances in technological knowledge generate output growth. There is, for example, no reason to expect multi-factor productivity to increase in industries outside the production of new technology. As already mentioned in Section 1, there is, however, a growing body of literature showing that the arrival of a new technology can generate a broad-based acceleration of productivity and growth. MFP is likely to increase also in industries using but not producing new technologies. The continuously declining prices of new capital goods create incentives for firms to use their other inputs in new, productivity-enhancing ways.

Such spillovers form the third channel through which a new technology can contribute to output growth. There is not yet any standard specification for the measurement of the spillover effect in the literature. Econometric estimation in various forms has been applied. David and Wright (1999, 2003) have estimated cross-industry regressions for electricity and Basu and Fernald (2006) for ICT. Stiroh (2002) has used panel data econometrics for ICT.

The approach used in the next two sections is based on estimating equations of the form

$$\Delta \ln A_{i,t} = \beta \Delta \ln K_{i,t,\mathrm{NT}} + \lambda_t + u_{i,t} \tag{4}$$

using panel data. Here λ is a dummy variable, u the residual, i refers to industry and t denotes time. A statistically significant β is used as a measure of the importance of spillovers. The spillover contribution is then obtained by multiplying the value of β by the average growth of new technology capital over the period and industries studied. This panel-data approach is here preferred to simple cross-industry regressions based on average growth rates since it gives more precise results.

3.2. The social savings approach

Growth accounting answers the simple *ex-post* question: How much did a new technology contribute to economic growth? The social savings approach addresses the counterfactual: How much faster was economic growth than it would have been in the absence of the new technology (Crafts, 2004a)? This method, pioneered by Fogel (1964), is based on estimating the cost savings from a new technology (for example, railroads) compared with the next best alternative (such as water transport). The savings in resource costs are then regarded to be equal to the gain in real national income.

In the growth accounting framework the natural interpretation of the gain in real income obtained from reducing real resource costs is an increase in multi-factor productivity (Crafts, 2004a; Field, 2006). This follows from the fact that MFP growth can be interpreted as real cost reduction using the price dual method.

Consequently, the social savings approach differs from the growth accounting approach in that it attributes to a new technology only the contributions arising through the first and third channels identified above.[3] The first one is the improvement of MFP in the industries producing new technology goods or services. The third channel consists of the possible MFP spillovers associated with the use of the new technology.

The social savings approach does not attribute any portion of the capital deepening effect to a new technology, arguing that it is attributable to saving. The reason is, as Field (2006) explains, that in a counterfactual world without the new innovation, but in other respects similar, saving flows would have funded the acquisition of other capital goods which were not quite as good. This would have resulted in lower capital accumulation but not by the full amount of the actual investment in new technology capital. Therefore, unless an argument can be made that the new technology raises the rate of return to investment at the margin and that the aggregate saving rate rises in response to this, the capital deepening effect should not be attributed to the new technology (Field, 2006: p. 99).

In the next two sections, growth accounting will be applied to measure the output contributions arising from the introduction of electricity and ICT in Finland. The findings will also be interpreted from the viewpoint of social savings.

4. Electricity as a source of output growth in 1900–1938

4.1. Electrifying Finnish production

Electric lighting was first demonstrated in Finland in 1877. Five years later the Finlayson cotton mill in Tampere installed incandescent lights. This was the fifth permanent installation in Europe. In 1888, the city of Tampere installed its own street lighting plants, and by the autumn of 1914 all 38 Finnish towns had one or more electric utilities (Myllyntaus, 1991).

At the turn of the century, mining and manufacturing formed a small sector of the economy but consumed most of the electricity generated in the country. The growth of the energy intensive forest and metal industries enhanced the demand for electricity by Finnish manufacturing. In the saw-milling industry, four mills installed electric lighting in 1882/3; by 1900 the number increased to more than 40 (approximately 7% of the saw-milling firms). The electrification of motive power was slower as electrical engines accounted for only 0.3% of the motive power in the saw-milling industry in 1900. The share slowly increased to 9% in 1910 and to 36% by 1920. In metal-working, the first machine shops used electric lighting by 1884, and at the turn of the century one third of the enterprises had electric lighting. The electrification of motive power proceeded rapidly from 4% of total motive power in 1898 to 47% in 1913, reaching 75% by 1920. In the pulp and paper industry, electric lighting was first used in the late 1880s. The electrification of motive power increased from 6% of total motive power in 1900 to 20% in 1910 and to 38% by 1920 (Myllyntaus et al., 1986).

The volume index of motive power grew at a compound average annual rate of 7.5% in the Finnish manufacturing industry in the period from 1900 to 1938 (Hjerppe et al., 1976). Before the Second World War, the industry was very energy intensive: in 1890–1938, an increase in industrial volume growth by 1% required a growth in electricity use by 3.5%. In the interwar period, the industry actually used 70–85% of all electricity output in Finland. The rise in electricity intensity slowed down in the 1949–67 period when increases of industrial output by 1% were accompanied by a growth of electricity use by 1.3% (Myllyntaus, 1991).

In an international comparison, Finland was not a latecomer but was in fact one of the leading countries in the electrification of mechanical drive in industry. To see this in greater detail, Fig. 2 compares the diffusions of electricity in manufacturing between Finland and the United States. It displays the shares of electricity in total motive power capacity. The electrification of manufacturing was very rapid in the United States from 1900 to 1939. The share of electric power increased from 5.6 to 85.5%. But electrification was equally rapid in Finland. Electricity's power share went up from 7.0 in 1900 to 87.3% in 1939.

[3] We would like to thank an anonymous referee for raising this issue.

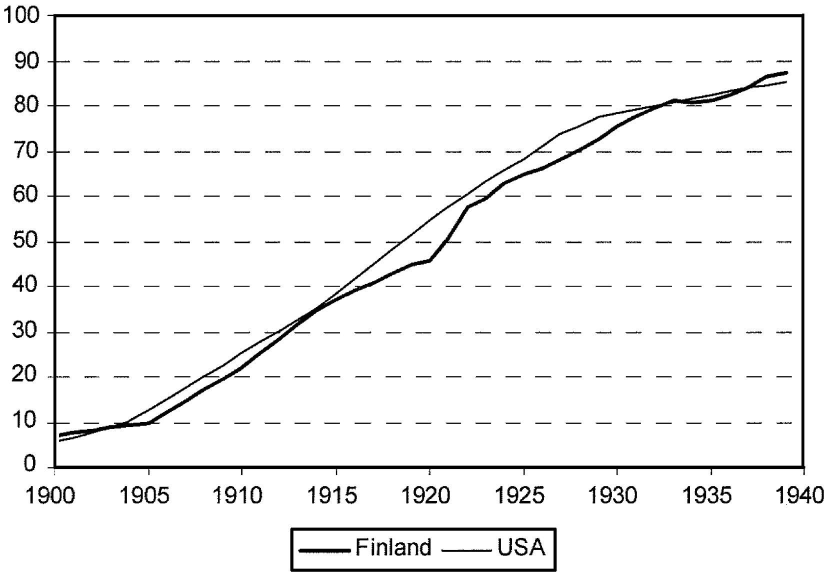

Fig. 2. Shares of electricity in total motive power in the U.S. and Finnish manufacturing, 1900–1939 (percent). Source: US data from DuBoff (1964) table 15 (intermediate years interpolated), Finnish data from Myllyntaus (1991) for years 1900–1920 and from Teollisuustilastoa SVT XVIIIA (i.e. the annual industry statistics publications) for years 1920–1939.

Industrialization started late in Finland. Agriculture accounted for 70% of employment in 1913. Industry's share was 10 and services' 20%. In Britain, the respective employment shares were 12, 44 and 44% (Broadberry et al., 2005). Much like in Japan, the age of steam power was in Finland historically compressed by the rapid process of the electrification of manufacturing. The transition to the new power regime happened at the same time as productive resources shifted from agriculture to manufacturing. One of the factors which contributed to the rapid adoption of electricity in a technologically backward country must have been the fact that there was not much existing manufacturing capacity based on old technology. The coexistence of older and newer forms of capital is known to have restricted the scope for exploiting electricity's potential in the United States (David and Wright, 2003).

4.2. *Electricity's growth effect*

The growth accounting framework (3) is here applied to assess the contribution of electricity to the growth of the Finnish GDP in the periods 1900–1913 and 1920–1938. The war years have been left out from the analysis. As shown in Table 1, the average output growth rate was 2.9% in the first period and 4.5% in the second.

Table 2 summarizes the findings.[4] Electricity's total contribution was rather low, 0.18 percentage points, in the first period. It picked up to 0.52 percentage points in the second period. The total contribution is obtained as the sum of the impacts arising from increases in electrical capital, from multi-factor productivity improvements in the production of electricity and electric machinery as well as from the multi-factor productivity spillovers resulting from electrical capital.

The capital contribution is estimated as in Crafts (2002) by dividing electrical capital into two components: electric utilities' capital stock and the stock of electrical capital goods. The data sources are documented in Appendix 1. As information on the income shares of the two components of electricity capital is not available, it is assumed that the income shares correspond to the capital stock shares. This means that the profits from owning these new forms of capital are assumed to be competitive rather than supernormal.

[4] The results are expressed in two decimal digits to minimize the impact of the rounding error, not to emphasize their accuracy.

Table 2
Electricity's contribution to the output growth of the Finnish non-residential market sector, 1900–1913 and 1920–1938

		1900–13	1920–38
Growth of real gross value added at basic prices[a]		2.91	4.53
Contribution[b] from	Capital	1.27	1.34
	Labour	0.64	0.88
	Multi-factor productivity	1.00	2.32
Total contribution[b] from electricity		0.18	0.52
Contributions from capital	Electric utilities' capital	0.07	0.29
	Electrical capital goods	0.04	0.03
Contributions from MFP	Electric utilities	0.05	0.19
	Electrical machinery	0.01	0.01
	Spillovers from the use of electrical capital goods	—	—
Memoranda			
Income shares[c]	Electric utilities capital	0.76	3.64
	Electric capital goods	0.47	0.48
Volume growth[a]	Electric utilities' capital	9.30	8.00
	Electrical capital goods	9.21	7.22
Output shares[c]	Electric utilities	0.51	2.24
	Manufacture of electrical machinery	0.24	0.31
Volume growth[a]	MFP of electric utilities	8.15	9.04
	MFP in the manufacture of electrical machinery	3.19	2.64

Sources. Own calculations; electric utilities income share and volume growth data from Tiainen (1994), electric capital goods volume growth data from Hjerppe et al. (1976) and income share from BEA applied on own capital stocks, electric utilities' and electrical machinery's output shares and MFP growth data from Tiainen (1994), see Appendix 1 for more details.

[a] ln %.

[b] ln percentage points.

[c] %.

The problem that information about electrical machinery's capital stock share is not available for Finland was solved by resorting to the U.S. data provided by the Bureau of Economic Analysis. It is assumed that the share of electrical machinery in equipment was the same in Finland as in the United States in the period considered.[5] This can be justified by referring to Fig. 2 which shows that the diffusion of electricity was as rapid in the Finnish as in the U.S. manufacturing. Data on capital share was obtained from Tiainen (1994). As shown in Table 2, the use of these two types of electrical capital goods contributed altogether 0.11 percentage points to output growth in 1900–13 and 0.32 percentage points in 1920–38.

As explained in Section 3.1, a new technology contributes to multi-factor productivity through its manufacturing and through the possible spillovers arising from its use. To estimate the first contribution, the multifactor-productivity growth rates of electric utilities and of the manufacturing of electrical machinery where multiplied by their shares in total output.[6] The combined contribution was 0.06 percentage points in the first period and 0.20 percentage points in the second. The contribution from the production of electrical machinery was very small (0.01 percentage points) in both periods reflecting its small share in output (about 0.3%.)

David and Wright (1999) have shown that large spillovers resulted from the widespread adoption of the electric unit drive in the U.S. manufacturing in the 1920s. Electrification was accompanied by new methods of power transmission and distribution as well as improvements in factory design and machine organization. David and Wright estimated the spillovers for a cross-section of manufacturing industries by regressing the observed acceleration of MFP growth on the increase in the share of aggregate direct factory drive represented by the capacity of secondary electric motors.

Their regression results imply that the spillovers contributed 2.4 percentage points per year to total manufacturing MFP growth. Crafts (2002) multiplied this number by the manufacturing sector's GDP share (0.3)

[5] BEA's Fixed Assets Tables are available on www.bea.gov. As the first year in this data is 1925, this year's share was used for the earlier years as well. This creates an upward bias to the estimate.

[6] The estimation method is explained and the details of the calculation are given in Appendix 1.

to obtain an estimate that electricity's MFP spillover contribution was 0.7 percentage points per year in the United States in the 1920s. As his estimate for electricity's total contribution to GDP growth is one percentage points per year, this means that spillovers accounted for 70% on the total contribution.

Our attempts to estimate the spillovers for Finland using David and Wright's (1999) approach failed, as did the attempts to apply Basu and Fernald's (2006) specification where the impact is delayed. In their cross-industry estimation of the ICT spillovers for the United Sates, Basu and Fernald argue that the spillover impact arises with a long lag and that, contemporaneously, investment in new technology can in fact reduce MFP growth as resources are diverted to reorganization and learning.

Better results were obtained by using the approach specified in Eq. (4). The multi-factor productivity growth rate was regressed on the increase in the capacity of electric motors and on year dummy variables using panel data from 15 manufacturing industries in 1921–38. The relationship is positive but statistically insignificant; the point estimate of β is 0.039 with p-value 0.144. As this p-value is above the conventional limit, the spill-over contribution is not included in Table 2. The finding may indicate that there indeed were no spillovers in Finland or it may just reflect the problems with the data.[7]

The data do not allow a distinction between power generated by the primary and secondary electric motors. Consequently, it is not possible in the analysis to capture the cross-section variation in the pace of diffusion of the group drive and unit drive systems. As David and Wright (1999) argue, the spill-over in the United States arose from changes in the internal power transmission arrangements within plants which the unit drive made possible.

To sum up, according to the growth accounting approach, electricity's overall contribution to GDP growth was 0.52 percentage points per year in 1920-38. Its capital contribution was 0.32 and MFP contribution in production 0.20. The MFP spillover contribution could not be identified. These numbers can be compared with Crafts' (2002) estimates for the United States in 1919–29. The total contribution was 0.98 percentage points of which 0.70 resulted from spillovers. Capital contribution was 0.23 and MFP in production contributed 0.05 percentage points. The largest difference is in the spillovers.

As explained in Section 3.2, the growth accounting approach overestimates the contribution arising from a new technology in the counterfactual sense. Without electricity economic growth would not have been 0.52 percentage points lower in Finland in 1920–38 but only 0.20 percentage points lower. This conclusion is obtained from the social saving approach which attributes only the MFP contribution to a new technology.

5. ICT as a source of output growth in 1980–2004

5.1. Digitalizing Finnish production

As was pointed out above, Finland was one of the leading countries in adopting electricity. This holds for telecommunications as well. The first telephone line was built in Helsinki in December 1877, only 18 months after the telephone was patented in the United States (Turpeinen, 1981). The Helsinki Telephone Corporation was established in 1882. There were already 3.3 telephone lines per 100 inhabitants in Helsinki in 1900, making it one of the major telephone cities in the world.

According to historians (e.g., Turpeinen, 1981), politics was one of the factors explaining the rapid adoption of the new communication technology.[8] When the telephone was invented, Finland was an autonomous Grand Duchy of the Russian Empire. The Finnish Telegraph Office was operated by the Russian authorities, but it was not clear who should grant permissions for operating the telephone. Upon application, the Senate of Finland decided that it has the right to do so. This decision was endorsed by Czar Alexander III, and it resulted in the establishment of private, regional telephone corporations all over the country. The statute the Senate issued made a sharp distinction between telephone and telegraph regulation and created a competitive telecommunications market. Just before World War II there were 815 telephone companies in Finland

[7] Edquist and Henrekson (2006) were not either able to find a clear correlation between labour productivity growth and the use of electric motors for manufacturing industries in Sweden.

[8] Castells and Himanen (2002: 56-57) provide a summary in English.

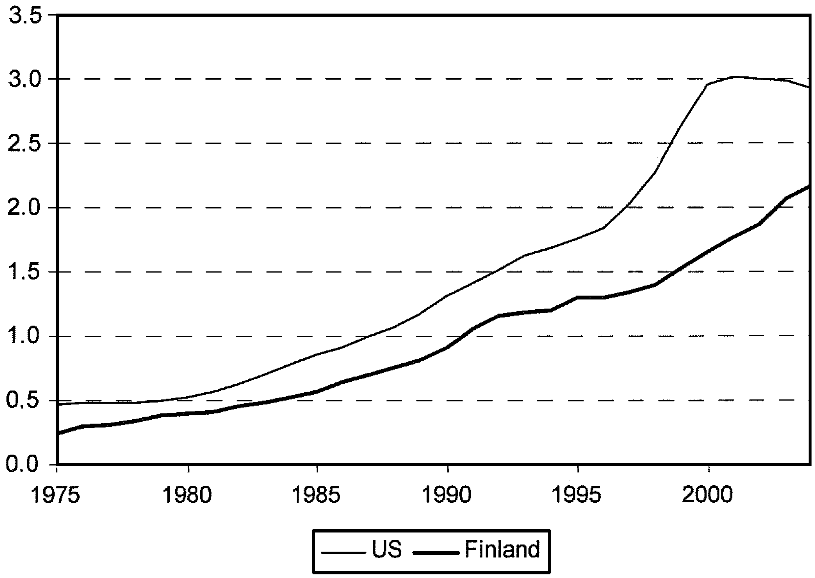

Fig. 3. Share of computer software in private, non-residential fixed assets, 1975–2004 (percent). Source: US data from the Bureau of Economic Analysis, NIPA Table 2.1; Finnish data from Statistics Finland.

whose population size was 3.6 million at that time. In most other countries, the telephone was considered to be a successor to the telegraph and thereby a state monopoly.

In 1961, the Helsinki Telephone Corporation started experimenting with data transmission systems. The first commercial connection was installed in a retail group in 1964 (Häikiö, 1995). The Finnish era of information technology had started a few years earlier when the first computer was purchased by the government-owned Post and Savings Bank in 1958 to oversee entries in savings accounts (Pukonen, 1993). The first Finnish computer was built in 1960 under the auspices of the Finnish Committee for Mathematical Machines (Andersin and Carlson, 1993).

In the early 1960s, a cable factory, Finnish Cable Works, with its 30 plus years of experience in manufacturing telecommunications cables, launched itself into the production of telecom equipment. It also set up a computing centre, which was the foundation of Nokia's electronics department, when in 1966 the company was merged with Nokia, a wood-pulp paper mill founded in 1865. In the early 1970s Nokia began manufacturing computers, which was a major part of Nokia until the computer division was sold to ICL-Fujitsu in 1991, and producing digital telephone exchanges. The electronics division did not become profitable until 1971 and it did not contribute significantly to Nokia's net sales until the late 1980s. The company's main emphasis shifted to electronics only in the 1990s (Häikiö, 2002; Jalava, 2004).

Finland is generally regarded as one of the leading information societies. For example, it ranks seventh in IDC's (2006) Information Society Index which measures the ability of 53 countries to participate in the information revolution. The country's telecommunications manufacturing industry is also competitive in the world market, Nokia's share of the global mobile phone market being close to 40%. This industry's share of non-residential market production was 5.9% and share of exports 19.9% in 2004.[9]

However, as displayed in Fig. 3, the diffusion of ICT has been slower in Finland than in the United States when measured by the share of computer software in private, non-residential fixed assets. This measure is more relevant for output and productivity growth comparisons than mere headcounts of computer or Internet users. It is also one for which official data for both countries exist. Comparing this diagram with Fig. 2, one is inclined to conclude that Finland has not adopted ICT as rapidly as it adopted electricity. Consequently, the contribution of ICT use to output growth should be smaller in Finland than in the leading ICT-using countries.

[9] For comparison, the respective shares for the paper and pulp industry were 4.4 per cent of production and 14.6 per cent of exports.

Table 3
Factor contributions to the output growth of the Finnish non-residential market sector, 1980–1990 and 1990–2004 ((a) estimates based on non-hedonic ICT prices, (b) estimates based on hedonic ICT prices)

		1980–1990		1990–2004	
		(a)	(b)	(a)	(b)
Growth of real gross value added at basic prices[a]		3.15	3.15	2.53	2.53
Contribution[b] from	Capital	1.10	1.32	0.37	0.53
	Labour	0.57	0.57	-0.35	-0.35
	Multi-factor productivity	1.48	1.26	2.51	2.35
Total contribution from ICT[b]		0.48	0.66	1.54	2.09
Contribution from ICT capital		0.22	0.44	0.24	0.43
Contributions from MFP	ICT production	0.26	0.22	0.91	0.89
	Spillovers from the use of ICT capital	—	—	0.39	0.77
Memoranda					
Income share of ICT capital[c]		2.45	2.62	4.63	4.62
Volume growth of ICT capital[a]		8.80	17.00	3.92	7.83
Output share of ICT production[c]		5.53	5.53	10.06	10.06
MFP growth in ICT production[a]		4.76	3.97	9.05	8.75

Sources. Column (a): the Finnish National Accounts and EU KLEMS database, column (b): EU KLEMS Database, March 2007, http://www.euklems.net, see Appendix 2 for more details.

[a] ln%.

[b] ln percentage points.

[c] %.

5.2. *ICT's growth impact*

Table 3 displays the results obtained by applying the growth accounting Eq. (3) and the spillover regression (4) to assess the contributions of information and communication technology to GDP growth in the non-residential market sector in 1980–2004. The year 1990 divides the overall period to two sub-periods in such a way that the latter period covers both the depression and the recovery from it. The data come from the recently established EU KLEMS database (www.euklems.net) which has been created for analyses of growth and productivity in the European Union and to which we have contributed by providing data on Finland. The non-residential market sector is comprised of 25 industries. For each industry, output is measured by the real gross value added and the inputs by capital and labour services. Both services are obtained by aggregating quality-adjusted input quantities over heterogeneous input types by using user costs as weights for capital assets and wage rates for hours worked (see Appendix 2 for details).

Two sets of estimates are presented. The first set in column (a) contains the results obtained using the official national accounts data for Finland which are not based on any hedonic prices for ICT investment. These results are here used to compare the growth impacts of ICT and electricity. As mentioned earlier, hedonic price indexes are not available for electricity. Using such prices for one technology and not for the other would create a measurement bias. The second set in column (b) is derived from the EU KLEMS dataset whose ICT investment data for Finland were created by using the hedonic indexes derived by Jalava and Pohjola (2007). These estimates are here used first to assess the impact of the quality adjustment on ICT's growth contribution and, second, to compare the Finnish numbers with those obtained for the United States whose estimates are based on hedonic prices.

Tables 2 and 3 reveal acceleration in the rate of output growth from the early twentieth century to the 1980s and then a deceleration thereafter. The contributions from capital and labor inputs stayed surprisingly constant during the sub-periods 1900–13, 1920–38 and 1980–90. Capital's contribution was in the range of 1.1–1.3 percentage points and labor's about 0.6 percentage points. In 1990–2004, the latter turned negative and the former declined to one third of its earlier level. The contribution of MFP has picked up. In the most recent period, it has been equally important as a source of growth as it was in the 1920s and 1930s. Much of its increasing role in growth derives from ICT.

According to the estimates based on the official national accounts (column (a)), ICT's overall contribution to GDP growth was 0.48 percentage points in 1980–1990 and 1.54 percentage points in 1990–2004. The largest contribution resulted from the improvement of multi-factor productivity in ICT production which here includes both the manufacturing of ICT equipment (electrical and optical equipment, industries 30–33) and the provision of post and telecommunication services (industry 64). The MFP contribution increased from 0.26 percentage points in the first sub-period to 0.91 points in the second. The contributions of ICT capital were about 0.2 percentage points in both sub-periods.

To estimate the spillover impact from ICT use, a number of approaches were tried. Cross-industry regressions of the average MFP growth rates on the average changes in ICT capital services did not produce any statistically significant correlations. The panel data approach specified in Eq. (4) was more successful. The relationship is positive and statistically significant; the point estimate of β is 0.155 (p-value 0.022) during 1990–2004 for the sub-sector of the non-residential market economy where, according to Nordhaus (2002), productivity can be measured well.[10] Here it is comprised of 21 industries covering agriculture, mining, manufacturing, electricity, gas and water, wholesale and retail trade, and transportation. The spill-over impact of 0.39 percentage points per year in Table 3 is obtained by multiplying the regression coefficient (0.155) by the average growth of ICT capital services (3.5%) and by the share (0.72) of this sector in the value added of the non-residential market economy. The finding is interesting since we are not aware of any strong evidence for ICT spillovers in other countries. The evidence is here also weak in the sense that it is obtained for period 1990–2004 and for the mentioned sub-sector of the market economy only. Moreover, the estimated effect has a rather poor fit (the adjusted R-square is 0.11). The relationship may also suffer from reverse causality.

Comparing Table 3 with Table 2, it is seen that ICT's contribution to GDP growth in 1990–2004 was three times as large as electricity's contribution in 1920–1938. These technologies also differ with respect to the relative importance of the sources of the growth contributions. The improvement of MFP in production accounted for 60% of ICT's contribution but only one third of electricity's. No evidence for spillovers from the use of electricity is found but the spillovers arising from the use of ICT amount to 25% of ICT's total contribution.

The estimates in column (b) of Table 3 are derived using ICT investment series based on hedonic prices. The contribution from ICT capital is now about 0.2 percentage points higher than in column (a) in both periods. The contribution arising from MFP growth in ICT production is not affected by the switch to hedonic prices. The spillover impact is about 0.4 percentage points higher in the latter period reflecting the fact that the measured growth of the volume of ICT capital is larger when hedonic prices are used.[11] Consequently, applying hedonic price indexes in the measurement of ICT capital services increases ICT's total growth contribution by about 0.2 percentage points in 1980–90 and by almost 0.6 percentage points in 1990–2004.

According to the EU KLEMS database (www.euklems.net) ICT's total contribution to GDP growth in US non-residential market sector was 0.88 percentage points in 1980–1990 and 1.23 percentage points in 1990–2004. The contributions from ICT capital were 0.54 and 0.70 and from MFP in ICT production 0.34 and 0.53, respectively. We were not able to find any evidence for positive spillovers from ICT use by running panel-data regressions (4).

Comparing these numbers with those for Finland in column (b) of Table 3 reveals that ICT's contribution has been greater in Finland in the latter period even without the spillover effect. The reason is the large contribution of MFP in ICT production reflecting Finland's specialization in the production of telecommunications equipment and services.

The overall growth contribution of ICT obtained from the growth accounting approach is large for Finland. But it is large even if the social savings approach is used. This holds especially for the period after 1990 during which ICT's MFP contribution has been substantial. Consequently, without ICT Finland's growth performance would have been much weaker.

[10] The number of observations is 294, and the adjusted R-squared is 0.11.

[11] The point estimate of β is 0.130 with p-value 0.039, and the adjusted R-squared is 0.26 which again is quite low.

5.3. What would have happened without ICT production?

The social savings answer to the question of what would have happened to Finnish growth without the ICT technology is that it would have been smaller by the amount of the MFP contribution arising from ICT. In 1990–2004, this was 1.30 percentage points per year. It consisted of the contribution from the MFP growth in ICT production at the rate of 0.91% and of the spillover contribution from ICT use at the rate of 0.39% when the non-hedonic prices are used in measuring ICT capital (column (a), Table 3).

In the following, the focus will be in the MFP growth contribution from ICT production. The spillover impact is left aside as it is rather uncertain and is based on an analysis of a sub-sector only. The counterfactual analysis is here taken a step further from the social savings approach by asking what would have happened to Finland had it not been as successful in ICT production as it has during 1990–2004. The social savings answer is that the growth rate would have been 0.91 percentage points lower. But had Finland not produced ICT, the resources would have been allocated to the production of something else, say paper and pulp. How much would growth have been affected?

According to the memoranda panel of Table 3, MFP increased at the annual rate of about 9 percent in ICT production. As its output share was 10 percent, the contribution of ICT production to GDP growth was 0.9 percentage points (0.91 in column (a)). Assume that this MFP growth reflects exogenous technological change in ICT production.

What would have happened if technology had advanced at a lower rate? Suppose that the rate would have been 3 percent per year which was the average MFP growth rate in the manufacturing sector, excluding electrical and optical equipment. Assuming that the output share would have stayed the same, the contribution of ICT production would have fallen from 0.9 percentage points to $0.1 \times (9 - 3) = 0.6$ percentage points.

When calculated in this way, the direct growth contribution of ICT production would not be 0.9 but 0.6 percentage points. But the slowing down of technological change has also an indirect impact on output through the decline in investment growth. Without knowing the savings rate or the preferences of the households, it is impossible to say exactly how the actual growth path would have been affected. But it possible to estimate the impact on the steady-state growth rate implied by the parameter values.

Let us write the growth accounting Eq. (3) in the aggregate form as $\Delta\ln Y = v_K\ \Delta\ln K + (1 - v_K)\ \Delta\ln L + \Delta\ln A$ where K denotes aggregate capital services, including both ICT and other capital services, and v_K is the share of capital income in output. At a steady state, output and capital grow at the same rate, $\Delta\ln Y = \Delta\ln K$. Consequently, $\Delta\ln Y = \Delta\ln L + \Delta\ln A/(1 - v_K)$. Regarding the growth rates of labour and MFP as well as the capital share as exogenous, the impacts of the changes in their values can be calculated.

In 1990–2004, the growth rate of labor services was −0.34%, the MFP growth rate 2.51% and the capital share was 0.32. Had the Finnish economy been at the steady state implied by these values, output would have grown at the rate of 3.35% which is considerably higher than the observed rate 2.53. In a counterfactual world without the MFP contribution from ICT production, the steady state growth would have been $0.6/(1–0.32) = 0.88$ percentage points lower. This happens to be quite close to the measured direct MFP contribution of 0.91 percentage points in column (a) of Table 3.

This simple counterfactual analysis applies to the impact of ICT production only. Therefore, the comparison is made with the contribution from MFP in ICT production and not with the overall contribution from ICT which is 1.54 percentage points in Table 3. More sophisticated approaches should be used to study other counterfactuals such as what would have happened to capital contribution had ICT prices not declined at the observed rate.

Admittedly, this approach is also in other respects a rather rough way of estimating the counterfactual impact. It is based on the average values of the parameters over the period considered and assumes income and output shares to be unaffected by the removal of the ICT production sector. To obtain more accurate estimates, a dynamic multi-sector general equilibrium model should be developed.

6. Conclusions

This paper studies electricity and ICT as engines of growth in the process of Finland's transformation from a backward agricultural nation in 1900 into a modern high-tech country with GDP per capita today comparable to Western Europe. Although being relatively poor at the time, Finland was not a latecomer but was in fact one of the leading countries in the electrification of mechanical drive in industry in the early twentieth century. Today, the country is generally regarded as one of the leading information societies. Its telecommunications manufacturing industry is competitive in the world market and one of the key drivers of economic growth. Interestingly, however, the diffusion of ICT has been slower in Finland than in the United States when measured by the share of computer software in private, non-residential fixed assets.

Using the growth accounting approach, it was shown that ICT's contribution to GDP growth was three times as large as electricity's contribution over comparable periods of time. The improvement of multi-factor productivity in production accounted for 60% of ICT's contribution but only one third of electricity's. Finland has thus been far more successful as an ICT producer than a producer of electricity.

The growth contribution of electricity was somewhat smaller in Finland than in the United States. The main source of the difference is the multi-factor productivity spillovers associated with the use of electricity. They were large in the United States but not observable in Finland.

Interestingly, the growth contribution of ICT has in Finland been higher than in the United States. The deepening of ICT capital has been important for the United States, improvement of productivity in ICT manufacturing for Finland. The spillovers for ICT use have also played an important role in Finland, although this evidence is only obtained for the sub-sector of the market economy where productivity is considered to be well measured.

The social savings approach to measuring the impacts of a new technology differs from the growth accounting approach in that it does not attribute any portion of the capital deepening effect to the new technology, arguing that it is attributable to saving. The measured growth contributions are therefore smaller when the social savings approach is used. But the qualitative conclusions obtained in the paper still hold: ICT has contributed more than electricity to Finnish economic growth, and electricity's contribution has been smaller and ICT's larger in Finland than in the United States.

During the period considered in this paper, Finland switched from resource-based to ICT-based growth. However, given the large dependency on the ICT-producing sector, the ongoing outsourcing of ICT production to low wage countries provides a threat to productivity performance in the future. Finland may have to restructure its economy once again in the digital era.

Appendix 1. Data sources and methodology for calculating electricity's contribution to the output growth of the Finnish non-residential market sector, 1900–1913 and 1920–1938

The contributions of electricity to output growth were calculated using Eq. (3) at the level of the Finnish non-residential market sector.

Electric utilities capital stock growth:

Calculated as the share of electricity in the capital stock (from Tiainen, 1994) multiplied by the nominal non-residential capital stock deflated by Tiainen's deflator.

Income share:

Calculated as the share of electricity in the capital stock (from Tiainen, 1994) multiplied by the income share of total capital.

Electric utilities capital contribution

The capital stock growth rate multiplied by the income share.

Electrical capital goods capital stock growth:

Index of installed power in large and medium scale manufacturing industry (from Hjerppe et al., 1976).

Income share:

Calculated as the ratio of electrical assets to non-residential equipment in the United States, obtained from BEA, multiplied by the share of machinery and equipment in the nominal non-residential capital stock.

Electrical capital goods contribution
The capital stock growth rate multiplied by the income share.

Electric utilities MFP growth:
Calculated as the geometric average of labor productivity growth and capital productivity growth using Tiainen's (1994) unpublished data on gross value added at 1995 prices, hours worked, average net capital stock at 1980 prices, and wages, salaries and employers' social contributions by industry.
Output share:
Industry's share in the gross value added of the non-residential market sector (from Tiainen, 1994).
Electric utilities MFP contribution
The MFP growth rate multiplied by the output share.

Electrical machinery MFP growth:
Calculated as the geometric average of labor productivity growth and capital productivity growth using Tiainen's (1994) unpublished data on gross value added at 1995 prices, hours worked, average net capital stock at 1980 prices, and wages, salaries and employers' social contributions by industry.
Output share:
Industry's share in the gross value added of the non-residential market sector (from Tiainen, 1994).
Electrical machinery MFP contribution
The MFP growth rate multiplied by the output share.

Capital stocks

Because data on industry-level investments by asset type were not available, the capital stocks were calculated at the non-residential market sector level. The total non-residential capital stocks were obtained using the perpetual inventory method with the assumption of geometric age-efficiency profiles:

$$K_t = K_{t-1}(1-d) + I_t = \sum_{\tau=0}^{\infty}(1-d)^{\tau} I_{t-\tau}.$$

Here K denotes the year-end real capital stock, I is investment, d is the rate of depreciation and t denotes time. The rates of depreciation used were: 0.03 for non-residential structures (Hulten and Wyckoff, 1996), 0.0152 for civil engineering and other structures (Fraumeni, 1997), 0.3 for transportation equipment (Hulten and Wyckoff, 1996), 0.12 for machinery and equipment (Hulten and Wyckoff, 1996). For non-residential buildings and civil engineering and other structures the building cost index and for the other asset types the wholesale price index was used as the deflator.

Appendix 2. Data sources and methodology for calculating ICT's contribution to the output growth of the Finnish non-residential market sector, 1980-1990 and 1990-2004

The methodology used in the EU KLEMS project (www.euklems.net) for growth accounting is the sources-of-growth methodology of Jorgenson, Gollop and Fraumeni (1987) as recently specified by Jorgenson, Ho and Stiroh (2005) (see Timmer et al., 2007, for the details). The industry level data were aggregated using the Törnqvist index (which was also used in the growth accounting computations).

Output

Output is measured by the real gross valued added at basic prices in the 25 industries comprising the non-residential market sector.

Capital services

Capital stocks (see the equation in Appendix 1) are calculated by asset type. Eleven asset types are identified: Residential structures, Non-residential structures, Infrastructure, Transport equipment, *Computing equipment, Communications equipment*, Other machinery and equipment, Products of agriculture and forestry, Other products, *Software*, and Other intangibles (the assets in italics are the ICT assets). The individual capital stocks by asset type are aggregated using the user costs (without the tax terms) as weights into a volume index of capital services (ex-post rates of return are used).

Two kinds of deflators for Finnish ICT assets are used: hedonic (the ones used in the EU KLEMS project) and non-hedonic (used to enable sensitivity analysis in this paper). Hedonic functions are relations between the prices of characteristics, such as computer speed, to the prices of the goods themselves. Because hedonic indexes are not available for ICT products in Finland, data from the US Bureau of Economic Analysis (BEA) were used. The methodology adopted, described in greater detail in Jalava and Pohjola (2007), is broadly that of Schreyer (2000). The annual changes in the BEA's price index for private non-ICT fixed investments were contrasted with the annual changes in the BEA's price indexes for computers, software and communication equipment, respectively. The four series thus obtained were first smoothed using the Hodrick-Prescott filter, after which they were multiplied with the implicit Finnish aggregate investment deflator to obtain the Finnish quality adjusted ICT deflators. The non-hedonic deflators used are the official Finnish national accounts' deflators.

Labor services

Hours worked and remuneration are distinguished by industry and by gender, age (15–19, 30–49, 50 and over) and education (high, medium, low). The labor compensations are used as weights in aggregating the labor hours per class into a measure of labor services.

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