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THE RESEARCH INSTITUTE OF THE FINNISH ECONOMY
Lönnrotinkatu 4 B 00120 Helsinki Finland Tel. 358-9-609 900
Telefax 358-9-601 753 World Wide Web: http://www.etla.fi/

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Jukka Jalava†

ELECTRIFYING AND DIGITALIZING THE FINNISH MANUFACTURING INDUSTRY: HISTORICAL NOTES ON DIFFUSION AND PRODUCTIVITY*

† Department of Economics, Helsinki School of Economics, P.O. Box 1210, FIN-00101 Helsinki, Finland. E-mail: jukka.jalava@hkkk.fi

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ABSTRACT: The diffusion of two general purpose technologies, electricity and ICT, in the Finnish manufacturing industry is observed. The full diffusion of electricity as motive power in the 1920s and 1930s led to a step-up of nearly 4 percentage points in manufacturing LP. Furthermore, all industries across the board gained in productivity. In contrast, when ICT was fully diffused by the end of the 20^{th} century yeast-like productivity gains were invisible. In fact, LP slowed down in many industries, the notable exception of which is the electric and electronic appliance industry that experienced a mushroom-like boost in its LP growth. When the labour productivity growth was decomposed into the contributions of internal productivity growth, the employment share effect and the cross term, we found that labour shifting to industries with differing levels or growth rates of LP explains less of aggregate LP change in 1920–1938 (and even less in 1974–2000) than it did in 1901–1920.

Key words: technology, electricity, ICT, manufacturing, diffusion, productivity

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TIIVISTELMÄ: Tarkastelemme kahden yleisteknologian, eli sähkön ja tieto- ja viestintäteknologian (ICT), diffuusiota Suomen tehdasteollisuudessa. Sähkön täysi leviämien käyttövoimana 1920- ja 1930-luvuilla johti lähes 4 prosenttiyksikön nopeutumiseen tehdasteollisuuden työn tuottavuuden kasvussa. Lisäksi tuottavuuden nopeutumista tapahtui kaikilla alatoimialoilla. ICT:n täysi diffuusio 1900-luvun lopulla ei aiheuttanut tuottavuuden hiivamaista nopeutumista tehdasteollisuuden alatoimialoilla. Työn tuottavuuden muutos jopa hidastui useilla alatoimialoilla. Poikkeuksena oli sähköteknisen toimialan kokema sienimäinen työn tuottavuuden kasvupyrähdys. Kun dekomponoimme työn tuottavuuden kasvun toimialojen sisäisen tuottavuuskasvun ja työpanoksen siirtymän vaikutuksiin, havaitsimme että työpanoksen siirtymä korkeamman työn tuottavuuden tason tai kasvuvauhdin toimialoille selittää vähemmän työn tuottavuuden muutoksesta vuosina 1920–1938 (ja vielä vähemmän 1974–2000) kuin vuosina 1901–1920.

Avainsanat: teknologia, sähkö, tieto- ja viestintäteknologia, ICT, tehdasteollisuus, diffuusio, tuottavuus

1. Introduction

Advanced economies are becoming more and more weightless[1], as the share of the production of tangible goods in GDP diminishes. Has something profoundly new taken place? I.e., is it so that we actually are in the midst of an information and communication technology (ICT) revolution, as ICT follows in the footsteps of steam and electricity as a general purpose technology (GPT)? Indeed, the quantification of ICT-capital deepening's contribution to labour productivity (LP) and that of ICT-capital services to growth has revived the interest for neoclassical growth accounting both in economics and economic history. Many a study has found ICT-use and/or ICT-production to contribute significantly to growth and productivity.[2]

Richard Lipsey, Cliff Bekar and Kenneth Carlaw, define a GPT as a technology that has scope for improvement, is widely used, has many uses, and has many complementarities with other existing or potential technologies.[3] Also Joel Mokyr stresses the historical importance of macroinventions, which he defines as: *"...technological breakthroughs that constitute discontinuous leaps in the information set and create new techniques"*.[4] These macroinventions are then followed and perfected by a string of microinventions. Paul Stoneman and Paul David emphasize the importance of the third part of the Schumpeterian trilogy, the two first of which are: invention (a new discovery) and innovation (*"the successful solution ... of putting an untried method into practice"*[5]*)*. In their view the diffusion of a new technology is what matters: *"What determines improvements in productivity and product quality, thereby enhancing economic welfare and the competitiveness of firms and industries, is not the rate of development of new technologies but the speed and extent of their application in commercial operations"*.[6]

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[1] Quah, Danny (2001): The Weightless Economy in Economic Development, in Matti Pohjola (ed.): *Information Technology, Productivity, and Economic Growth*, Oxford: Oxford University Press.

[2] See e.g. Oliner, Stephen E. and Sichel, Daniel E. (2000): The Resurgence of Growth in the Late 1990s: Is Information Technology the Story?, *Journal of Economic Perspectives,* Volume 14 (4), pp. 3-22, Jorgenson, Dale W. and Stiroh, Kevin J. (2000): Raising the Speed Limit: US Economic Growth in the Information Age, *Brookings Papers on Economic Activity,* Vol. 1, pp. 125-211, Daveri, Francesco (2002): The New Economy in Europe, 1992-2001, *Oxford Review of Economic Policy*, Vol. 18 (3), pp. 345-362, van Ark, Bart, Melka, Johanna, Mulder, Nanno, Timmer, Marcel and Ypma, Gerard (2002): *ICT Investment and Growth Accounts for the European Union, 1980-2000*, mimeo, and Jalava, Jukka & Pohjola, Matti (2002): Economic Growth in the New Economy: Evidence from Advanced Economies, *Information Economics and Policy,* Vol. 14 (2), pp. 189-210.

[3] Lipsey, Richard G., Bekar, Cliff and Carlaw, Kenneth (1998): What Requires Explanation?, in Elhanan Helpman (ed.): *General Purpose Technologies and Economic Growth*, Cambridge, Massachusetts and London: The MIT Press.

[4] Mokyr, Joel (1990): Punctuated Equilibria and Technological Progress, *The American Economic Review,* Volume 80 (2), pp. 350-354.

[5] Schumpeter, Joseph (1928): The Instability of Capitalism, *The Economic Journal,* Vol. 38, No. 151, pp. 361-386.

[6] Stoneman, Paul L. and David, Paul A. (1986): Adoption Subsidies vs Information Provision as Instruments of Technology Policy, *The Economic Journal,* Vol. 96, Supplement Conference Papers, pp. 142-150.

In an empirical study on three GPTs: steam, electricity and ICT, Nicholas Crafts finds, when analyzing UK and US data, that ICT has contributed more to growth than steam and at least as much as electricity, in similar, early stages of diffusion.[7] However, after a new technology is fully diffused there might be a considerable lag of 5 to 15 years before the productivity effects emerge. The productivity literature usually sees the productivity effects of the adoption of a new technology as threefold. Firstly, productivity growth picks-up in the industries producing the new technology due to rapid technological advances. Secondly, productivity increases take place in industries using the new technology through capital deepening as the old capital is gradually substituted by new capital, and thirdly, the using industries experience multi-factor productivity increases as new organizational models emerge and the new technology is followed by incremental product and process innovations.

Needless to say, technology is not the whole story. Human capital[8] and R&D expenditure[9] should be seen as vital parts of the modern economy's toolbox. Pinpointing the contributions to productivity of innovations, improvements of corporate governance or logistics is also an important task for the economic historian. The availability/unavailability of venture capital for new start-ups, and more generally the impact of competition for necessary micro-level structural changes should not be forgotten either. Indeed, for Finnish manufacturing there is by now ample evidence gathered by Mika Maliranta that during the early 1990s recession productivity improving creative destruction took place.[10]

In this paper our aim is to review and compare the historical evidence of the effects of electrifying and digitalizing the Finnish manufacturing industry. What were the impacts of the diffusion of these two GPT's on the productivity of Finnish manufacturing? Section 2 starts by tracing the introduction and diffusion of electricity in the Finnish manufacturing industry and section 3 does the same for ICT. In section 4 are shown the growth decompositions and section 5 concludes.

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[7] Crafts, Nicholas (2002): The Solow Productivity Paradox in Historical Perspective, *Centre for Economic Policy Research (CEPR)*, Discussion Paper No. 3142, January.

[8] See e.g. Aulin-Ahmavaara, Pirkko (2002): Human Capital as a Produced Asset, paper presented at the *27th General Conference of the International Association for Research in Income and Wealth (IARIW),* Stockholm, Sweden, August 18-24.

[9] See e.g. Rantala, Olavi (2003): Tuotekehitys, toimialojen panos-tuotosrakenteen muutokset, tuottavuus ja talouden kasvu", *The Research Institute of the Finnish Economy (ETLA)*, Discussion Paper No. 842, January.

[10] Maliranta, Mika (2003): *Micro Level Dynamics of Productivity Growth*, *An Empirical Analysis of the Great Leap in the Finnish Manufacturing Productivity in 1975-2000*, mimeo, The Research Institute of the Finnish Economy (ETLA).

2. Electrifying the production process

William Gilbert (1544-1603), a physician to Elizabeth I, was the first person to distinguish between magnetic and electrical attractive forces. The word electricity is derived from the Greek word *ilektro*, which means amber (amber acts like a magnet attracting small objects when rubbed). His major work *De magnete* was published in 1600. Six decades later the German scientist Otto von Guericke started experimenting with *static electricity*, and finally discovered *electroluminescence* in 1672. von Guericke was followed by Stephen Gray, who in the 1720s conducted electricity down a string of silk, thus realizing that electricity could be transmitted from one object to another object. He furthermore showed that the material of the string influenced the conductance.[11]

In the 1790s Luigi Galvani experimented with frogs, and found that an electric current is produced when two different metals touches a frog's muscle. Later that same decade Alessandro Volta showed that the same phenomenon occurs when two metals are put into a conducting fluid, i.e. he invented the first battery. Using batteries the Dane Hans Christian Oersted discovered *electromagnetism* in 1819, and improving on Oersted's discovery the following year Michael Faraday found that also magnetism can cause electricity in experiments on *electromagnetic rotation* that he performed. These experiments led him in 1831 to discover the *dynamo.* In 1879 Thomas Alva Edison patented the *incandescent light bulb.*[12]

In Finland the first demonstration of electric lighting was made in 1877. Five years later the Finlayson cotton mill in Tampere installed Edison's incandescent lights. This was the fifth permanent installation in Europe. The earlier ones were in London, Paris, Milan and Strasbourg. In 1888 the city of Tampere and in 1890 the city of Oulu installed local government owned street lighting plants, and by the autumn of 1914 all 38 Finnish towns had at least one electric utility.[13]

In the saw-milling industry 4 mills installed electric lighting already in 1882-1883, which by 1900 increased to more than 40 mills (about 7 per cent of the firms). The electrification of the motive power of saw-mills was slower. Electrical engines accounted for only 0.3 per cent of the motive power in the saw-milling industry in 1900[14], which slowly increased to 9 per cent in 1910 and 36 per cent in 1920. In the

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[11] See Windelspecht, Michael (2002): *Groundbreaking Scientific Experiments, Inventions and Discoveries of the 17th century*, Westport, CT: Greenwood Publishing Group, and Hager, Alan (ed.) (1997): *Major Tudor Authors: A Bio-bibliographical Critical Sourcebook*, Westport, CT: Greenwood Publishing Group.

[12] Rozakis, Laurie (2001): *The Big Book of Dates*, McGraw-Hill.

[13] Myllyntaus, Timo (1991): *Electrifying Finland: The Transfer of a New Technology into a Late Industrialising Country*, London: Macmillan & ETLA.

[14] From 1860 to 1900 saw-mills shifted from using water power to thermal power as energy sources. This freed the mills of the geographical constraint of having to be located next to rivers. See: Hoffman, Kai (1980): *Suomen sahateollisuuden kasvu, rakenne ja rahoitus 1800-luvun jälkipuoliskolla*, Bidrag till kännedom av Finlands natur och folk, H. 124, Helsinki: The Finnish Society of Sciences and Letters.

metal industry the first machine shops were using electric lighting in 1884. By the turn of the century approximately a third of the metal industry's enterprises had electric lighting. The electrification of the motive power in the metal industry increased rapidly from 4 per cent of total motive power in 1898 to 47 per cent in 1913 and 75 per cent in 1920. In the paper and pulp industry the first steps towards electric lighting were taken in the late 1880s. The electrification of the motive power in the paper and pulp industry increased from 6 per cent of total motive power in 1900 to 20 per cent in 1910 and 38 per cent in 1920.[15] The volume index of motive power grew in the Finnish manufacturing industry from 1900-1938 at a compound average annual rate of 7.5 per cent. The growth was particularly rapid in manufacture of chemicals etc. (10.0 per cent), in manufacture of leather, leather products and rubber products (10.0 per cent), in food, beverage and tobacco industries (9.7 per cent), in manufacture of non-metallic mineral products (9.1 per cent), in manufacture of paper and pulp (8.9 per cent) and in printing and publishing (8.4 per cent).[16] Before WWII the Finnish industry was very energy intensive, an increase of one per cent in volume growth required a growth of 3.5 per cent in electricity use between 1890 and 1938.[17]

The full diffusion of electric motors in the motive power of Finnish total industry took place during the 1920s and 1930s. In the year 1913 the share was 32 per cent, in 1925 already 63 per cent and in 1938 as much as 87 per cent. In comparison, the diffusion of electric motors as source of mechanical drive in the U.S. manufacturing industry was 25 per cent in 1909, 53 per cent in 1919, 78 per cent in 1929 and 86 per cent in 1939.[18] Thus we observe that the pace of diffusion of electricity in the Finnish manufacturing process bears close resemblance to that of the U.S.

As parliament in the early 1920s decided to build more hydropower electrical plants, consequently transmission lines had to be built, which laid the foundation for the national network of transmission lines, and therefore a switch from half to three-quarters of the electricity output coming from hydropower (of the country's total electricity supply manufacturing actually used 70-85 per cent) took place. In the interwar period also the power distribution system of Finland was significantly extended, as the length of transmission lines increased from 7,406 kilometers in 1923 to 18,016 kilometers in 1938.[19]

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[15] Myllyntaus, Timo, Michelsen, Karl-Erik and Herranen, Timo (1986): *Teknologinen muutos Suomen teollisuudessa 1885-1920: Metalli-, saha- ja paperiteollisuuden vertailu energiatalouden näkökulmasta*, Bidrag till kännedom av Finlands natur och folk, H. 134, Helsinki: The Finnish Society of Sciences and Letters.

[16] Hjerppe, Reino, Hjerppe, Riitta, Mannermaa, Kauko, Niitamo, O. E. and Siltari, Kauko (1976): *Suomen teollisuus ja teollinen käsityö 1900–1965,* Studies on Finland's Economic Growth VII, Helsinki: Bank of Finland Publications.

[17] Myllyntaus: *Electrifying Finland.*

[18] Devine, Warren D. Jr. (1983): From Shafts to Wires: Historical Perspective on Electrification, *The Journal of Economic History,* Volume 43 (2), pp. 347-372.

[19] Herranen, Timo (1996): *Valtakunnan sähköistyskysymys: Strategiat, siirtojärjestelmät sekä alueellinen sähköistys vuoteen 1940*, Bibliotheca Historica 14, Helsinki: Suomen Historiallinen Seura, and Myllyntaus: *Electrifying Finland.*

Warren Devine traces the evolution of power distribution in U.S. manufacturing plants. In the *direct drive* system, production machines were directly linked to the power sources. In most cases one machine supplied the power for an entire factory with pulleys and leather belts. This severely constrained the physical design of the factories as well as imposed restrictions on the organization of work, and in case of power failures or servicing the entire plant stood still. In the following stage the machine that drove the line shaft was simply changed to an electric motor, in the *electric line shaft drive*. The next step was the *electric group drive*, where the factories single giant line shafts were replaced by many shorter line shafts with electric motors connected to groups of production machines. Finally, in the *electric unit drive* system individual production machines were connected to electric motors.[20]

Paul David and Gavin Wright attribute the slow diffusion of electricity[21] in the U.S. to the long lag in profits accruing from implementing the new technology in production, which was due to the unprofitability of scrapping existing factories and the capital and production systems they embodied (similarly, there was not enough incentive in the Finnish saw-milling industry to rapidly adopt electricity and new labour saving technology in production, as the cost of raw materials and labour was low until the First World War[22]). However, when the increased use of electric motors was well underway a step-up in the labour productivity of the U.S. manufacturing sector of 4.5 percentage points from 1909-1919 to 1919-29 (to an annual average of 5.6 per cent) is to be observed.[23] Devine sees the ensuing productivity increases as resulting from: an increased flow of production, an improved working environment, improved machine control and increased ease of plant expansion.[24] After WWI power capital was substituted for other capital, which markedly increased capital productivity.[25] Not to be forgotten is the protectionist stance the U.S. took in the interwar era, thus avoiding the problems many export-oriented countries had. The U.S. domestic market grew quite sufficiently to ensure fast productivity growth.[26]

In 1860 only 4 per cent of the Finnish population worked in industry and handicraft, which managed to generate 7-8 per cent of GDP at basic prices. Half a century later a tenth of the economically active population was in industry, and as industrial output grew faster than GDP, the share of industry and handicraft in total output was

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[20] Devine: From Shafts to Wires.

[21] Slow since the first time electricity was used for driving machinery in U.S. manufacturing was already in 1883, see: Devine: From Shafts to Wires.

[22] Myllyntaus, Michelsen and Herranen: *Teknologinen muutos.*

[23] David, Paul A. and Wright, Gavin (1999): *Early Twentieth Century Productivity Growth Dynamics: An Inquiry into the Economic History of "Our Ignorance",* University of Oxford Discussion Papers in Economic and Social History Number 33, October.

[24] Devine: From Shafts to Wires.

[25] Du Boff, Richard B. (1966): Electrification and Capital Productivity: A Suggested Approach, *The Review of Economics and Statistics,* Vol. 48 (4), pp. 426-431.

[26] Nelson, Richard R. and Wright, Gavin (1992): The Rise and Fall of American Technological Leadership: The Postwar Era in Historical Perspective, *Journal of Economic Literature,* Volume 30 (4), pp. 1931-1964.

one fifth in 1913.[27] By 1938 total industry's share in GDP had increased to almost one quarter. Industry's contribution to GDP growth was even higher, i.e. 39 per cent on average 1920-1938. Primary production lost its position as the Finnish economy's growth engine after the 1890s, but from 1890-1913 primary production, secondary production and tertiary production still did not differ significantly in growth contributions. Starting with the 1920s began the rapid decline of primary productions growth contribution and the pre-eminence of secondary production. Tertiary production did not take the lead in contributions to growth until the 1960s.[28] Sakari Heikkinen and Riitta Hjerppe sum up the Finnish model of industrialization as follows: the country's main assets were the vast forests and hydropower potential as well as a labour reserve in the rural areas, export demand was crucial from the 1860s to the 1880s, during the unfavorable export conditions from the mid-1880s to the mid-1890s an increase in domestic demand and a growing domestic market share in industry was favorable for growth, from the 1890s until WWI both exports (the forest sector) and domestic markets contributed to growth, wood processing was crucial for the economy as it was an export industry with multiplier effects in primary production and transportation, and the international price development was favourable for Finland as the terms-of-trade increased approximately 100 per cent from the end of the 1860s to the early 20th century.[29] Timo Myllyntaus also points out the crucial role of electrification as a catalyst for modernization and introduction of productivity enhancing technical innovations.[30] As the 20th century's two first decades with a compound annual average increase in manufacturing LP of only 0.3 per cent turned into the 1920s and 1930s, with the diffusion of electricity nearing completion, the step-up in LP growth was 3.9 percentage points (to 4.2 per cent per year). The best performer in LP growth in 1920-1938 was the paper and pulp industry with 7.9 per cent (see Table 1). However, all observed manufacturing subindustries increased their LP growth, with especially printing and publishing, paper and pulp, the metal industry, manufacture of leather and miscellaneous manufacturing making the largest absolute improvements.

The investments into electrification were mainly financed by the industrial firms independently or through bank loans. Private power utilities and/or distribution companies issued shares to acquire financing and municipalities used tax revenues (or other income).[31] Although financial capital was not to a significant degree obtained from abroad (the role of foreign direct investment was small due to strong Finnish economic nationalism[32]), instead foreign experts were often encouraged to

[27] Heikkinen, Sakari and Hjerppe, Riitta (1986): *Suomen teollisuus ja teollinen käsityö 1860–1913,* Studies on Finland's Economic Growth XII, Helsinki: Bank of Finland Publications.

[28] Hjerppe, Riitta (1988): *Suomen talous 1860-1985, kasvu ja rakennemuutos,* Studies on Finland's Economic Growth XIII, Helsinki: Bank of Finland Publications.

[29] Heikkinen and Hjerppe: *Suomen teollisuus.*

[30] Myllyntaus: *Electrifying Finland.*

[31] Myllyntaus: *Electrifying Finland.*

[32] Myllyntaus, Timo (1992): Technology Transfer and the Contextual Filter in the Finnish Setting: Transfer Channels and Mechanisms in a Historical Perspective, in Vuori, Synnöve and Ylä-Anttila, Pekka (eds.): *Mastering Technology Diffusion – The Finnish Experience,* ETLA B:82, Helsinki: Taloustieto Oy.

join companies that adopted new technology.[33] Finns also studied abroad before the domestic technical education gained momentum. The educational aspect was always at the forefront. Imported turnkey technology construction was not sought after. Usually the more cumbersome road of Finnish firms participating in installing as much of the new technology as feasible was chosen.[34]

Table 1 Output per employment in manufacturing, compound average annual growth

	1901–1920 %	**1920–1938 %**	**1920–1938 less 1901–1920 %-points**
Manufacturing	**0.3**	**4.2**	**3.9**
Food, bev. and tobacco	0.3	3.3	3.0
Man. of textiles etc.	0.3	1.1	0.8
Man. of wood etc.	0.2	2.7	2.5
Paper and pulp	3.0	7.9	4.9
Printing and publishing	-1.2	4.0	5.2
Man. of leather etc.	-0.9	3.7	4.6
Man. of chemicals etc.	3.2	5.0	1.8
Man of non-met. mineral prod.	1.0	4.2	3.2
Metal industry	-0.7	4.2	4.9
Misc. manufacturing	0.6	4.9	4.3

Source: Own calculations, data from Hjerppe, Hjerppe, Mannermaa, Niitamo and Siltari (1976).

Due to data availability shortcomings we unfortunately cannot perform a LP comparison for the main electricity producing industry (the electricity, gas and water supply industry), for the same period as we did for the manufacturing industry. However, from Stats Finland's Historical National Accounts Database we extracted data from 1914 to 1938 that enabled us to compute the annual LP growth in the period 1915-1938. We found that the compound average annual LP growth in 1915-1920 was 8.2 per cent and that it was 10.7 per cent in 1920-1938. This finding is in accordance with the productivity literature's view of productivity gains first emerging in the industries that produce a new technology.

[33] Hjerppe: *Suomen talous.*

[34] Myllyntaus: *Electrifying Finland.*

3. The digital revolution

Gottfried Wilhelm von Leibniz (1646-1716), a German mathematician and philosopher invented the binary system of notation in 1679. The binary system was fundamental for the invention of electronic calculating machines, the first completely electronic computer the ENIAC in 1946 and eventually all computers.[35] The ENIAC used 18,000 *vacuum tubes*, which had the awkward tendency of burning out ever-so-often. In addition, the warmth and glow of the tubes attracted moths which caused short circuits.[36] The problem of overheating was solved by the invention of the *transistor* (made of the semiconducting material germanium, later also silicon was used) in 1947 by William Shockley, Walter Brattain, and John Bardeen at Bell Labs. In the year 1959 Jack Kilby at Texas Instruments invented the microchip, the first *integrated circuit* to defeat the "tyranny of numbers" that had hitherto constrained technical progress.[37] In 1971 Intel created the *microprocessor*, and the fourth generation of computers was born. Other important milestones in the development of ICT were the use of fiber optics to transmit data in 1966, the invention of ARPANET (the first computer network) in 1969 by the U.S. Department of Defense, the creation of the future leading software company Microsoft in 1975, the first testing of cell phones in 1978, the selling of personal computers to the general public by IBM in 1981, the selling of cell phones to the general public by Motorola in 1984, and the invention of the World Wide Web in 1989.[38]

In introducing the computer in Finland, the role of the Finnish Committee for Mathematical Machines was crucial. The committee started its work in 1954 with the objective of establishing the need for mathematical machines and to make recommendations of purchase or construction. The decision was taken to copy a computer designed in Göttingen, the G1a. What the committee was unaware of was that the G1a was still only a blueprint, and therefore what had been intended to be a quick one-and-a-half year long task of duplication actually turned into a construction and design of the computer. Thus the completion was delayed until 1960, when a by then outdated computer was presented to the University of Helsinki. The acronym ESKO, derived from Elektroninen Sarja KOmputaattori, was chosen for the Finnish venture that turned out to be the only G1a that was actually completed.[39] Although the ESKO was a failure in a technical sense, it played an important educational role as the first effort by Finnish engineers to study computer technology.[40] While the ESKO project was ongoing the Government owned Postisäästöpankki

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[35] Windelspecht: *Groundbreaking Scientific Experiments.*

[36] Hence the term debugging when attending to computer related problems.

[37] Reid, T. R. (2001): *Chip: How Two Americans Invented the Microchip and Launched a Revolution*, Westminster, MD: Random House Adult Trade Group.

[38] Rozakis: *The Big Book of Dates*.

[39] Andersin, Hans and Carlson, Tage (1993): ESKO – ensimmäinen suomalainen tietokone, in Tienari, Martti (ed.): *Tietotekniikan alkuvuodet Suomessa*, Jyväskylä: Gummerus Kirjapaino Oy.

[40] Paju, Petri (2003): *A Failure Revisited: The First Computer Construction and the Establishing of a National Computer Center in Finland*, mimeo, University of Turku.

(Post and Savings Bank) purchased from IBM the IBM 650 computer which was delivered in the autumn of 1958. Finland's first computer was quite fittingly christened ENSI (first, earliest). The primary objective of the ENSI was to oversee the entries in the savings accounts. Although the ENSI did not altogether replace the punched cards, it simplified and rationalized many stages of work.[41] Both the ESKO and the ENSI were first generation computers.[42]

The International Business Machine Corporation (IBM) had a strong position in Finland. Its predecessor (the Computing-Tabulating-Recording Company changed its name to the International Business Machine Corporation in 1924[43]) had already in 1922 supplied the first punch card machines to Finland, to Statistics Finland. The subsidiary IBM Finland was founded in 1936, and it consolidated its position as a supplier of punch card machines, precision instruments and electrical typewriters. IBM Finland founded a computing center, what they called a service bureau, in 1939. However, in the beginning there were no machines in the center. In the 1960s the service bureau entered a new era when it used IBM 1401's to cater for the needs of customers. The success of IBM Finland is represented by the increase in its employees. In 1951 the company employed 48 persons in Finland, in 1961 approximately 200 and in 1964 about 500.[44] IBM also dominated the market in the U.S. In 1965 it had a market share of 65 per cent and the second, Sperry Rand (that manufactured the ENIACs successors UNIVACs) had merely 12 per cent. By 1987 IBM became the third largest industrial corporation in the U.S.[45]

One of the two original engineers that had started to build the ESKO, Tage Carlsson, was in 1960 hired by Suomen Kaapelitehdas Oy (Finnish Cable Works).[46] The other one, Hans Andersin had earlier gone to work for IBM Finland. Kaapelitehdas was one of the three companies that in 1966 merged to form Oy Nokia Ab.[47] Kaapelitehdas had in 1958 decided to explore the possibility of starting to sell electronics (with the long-term plan of eventually constructing computers), and therefore it the following year acquired the majority of the stocks in an electronics importer, Chester Oy, that represented Texas Instruments, Isotope Developments etc. in Finland. In 1960 Kaapelitehdas decided to set up a computing center, which laid the foundation for Nokia's electronics department. The first computers the center purchased were the Elliot 803 and the Siemens 2002, which were operational in 1960 and 1961 re-

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41 Pukonen, Reijo (1993): Automaattisen tietojenkäsittelyn ENSI-askeleet Suomessa (Postipankin ENSI-tietokone), in Tienari, Martti (ed.): *Tietotekniikan alkuvuodet Suomessa*, Jyväskylä: Gummerus Kirjapaino Oy.

42 Seppänen, Jouko (1993): 30 vuotta tietokoneaikaa Teknillisessä korkeakoulussa, in Tienari, Martti (ed.): *Tietotekniikan alkuvuodet Suomessa*, Jyväskylä: Gummerus Kirjapaino Oy.

43 Pusateri, C. Joseph (1988): *A History of American Business*, Arlington Heights, IL: Harlan Davidson.

44 Dickman, Klas (1993): Uudet tuotteet – tuttu ympäristö, in Tienari, Martti (ed.): *Tietotekniikan alkuvuodet Suomessa*, Jyväskylä: Gummerus Kirjapaino Oy.

45 Pusateri: *A History of American Business.*

46 Aaltonen, Aarne (1993): Nokian elektroniikkateollisuuden synty: nuorten kokeilijoiden ja keksijöiden pajasta huipputeollisuudeksi, in Tienari, Martti (ed.): *Tietotekniikan alkuvuodet Suomessa*, Jyväskylä: Gummerus Kirjapaino Oy.

47 Häikiö, Martti (2002): *Nokia: The Inside Story,* Helsinki: Edita.

spectively.[48] The idea was to sell services to clients, and later on computers as the clients' needs grew. The Elliot 803 was a fully transistorized second generation computer and it had been purchased to take care of scientifically and technically oriented customers and the Siemens 2002 was meant to service administrative and commercial clients.[49] In the early 1960s the Cable Works, which had a 30 plus years of experience of manufacturing telecommunications cables, launched itself into the production of telecom equipment. The development work was divided into three groups: microwave technology, UHF- and radiophones, and carrier-wave technology. An important customer was the Finnish Defense Forces. In the mid-1960s the Cable Works started to supply alarm systems to power utilities and register systems to saw-mills. The company also designed dataloggers for manufacturing and power production and distribution systems in co-operation with power plants.[50] In the early 1970s Nokia started manufacturing computers (computer production was a major part of Nokia until it was sold to ICL-Fujitsu in 1991), and digital telephone exchanges. The beginning of the electronics division was humble as it did not contribute significantly to Nokia's net sales until the late 1980s (actually electronics did not become profitable until 1971), and it was not until the 1990s that Nokia started focusing on electronics.[51]

The diffusion of ICT in Finnish manufacturing was three-phased. Firstly, in the 1960s and 1970s firms started using ICT for administrative purposes. Secondly, in the 1970s and 1980s ICT found its way into manufacturing processes. By the beginning of the 90s close to half of the manufacturing firms used ICT in their production processes, and the use was more than average in the paper and pulp industry, the printing and publishing industry, and the chemical industry. Finally, in the 1980s and 1990s ICT was embedded into the manufactured products. The main driver in adopting the new technology was the desire to decrease production costs, to improve process and product quality, and to ensure reliable operations and delivery.[52] By the year 2001 ICT had diffused widely in the manufacturing industry. Of the firms 96 per cent used computers, 91 per cent used the internet, 59 per cent had homepages, 42 per cent used broadband connections, 27 per cent used intranet, 10 per cent extranet and 12 per cent EDI. For all enterprises the corresponding statistics were: 95 per cent used computers, 90 per cent used the internet, 51 per cent had homepages, 39 per cent used broadband connections, 24 per cent used intranet, 10 per cent extranet and 10 per cent EDI. Of all firms the share of firms where at least a quarter of the employees working time was spent using computers was 69 per cent in 2001.[53] That statistics had been only 17 per cent in 1984, 44 per cent in 1990 and

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[48] Aaltonen: Nokian elektroniikkateollisuuden synty.

[49] Seppänen: 30 vuotta tietokoneaikaa.

[50] Aaltonen: Nokian elektroniikkateollisuuden synty.

[51] Häikiö: *Nokia*.

[52] Jaakkola, Hannu (1992): The Diffusion of Information Technology in Finnish Industry: State of the Art & Analysis, in Vuori, Synnöve and Ylä-Anttila, Pekka (eds.): *Mastering Technology Diffusion – The Finnish Experience,* ETLA B:82, Helsinki: Taloustieto Oy.

[53] Statistics Finland (2002): *Internet Use and E-commerce in Enterprises*, Official Statistics of Finland: Science, Technology and Research 2002:4, Helsinki: Statistics Finland.

66 per cent in 1997. Thus by the turn of the millennium the Finnish workplace had quite extensively been computerized.[54] Micro-level evidence from the end of the 1990s indicate that the diffusion of ICT-use in firms was a within firm story (and not so much one of restructuring), with especially young ICT-intensive firms having stronger productivity impacts.[55]

A step-up in the manufacturing industry's LP was to be seen in the 1990s (see Table 2). However, the increase did not take place across the board for all industries as the case was when electricity was adopted. LP growth actually slowed down in the leather industry, metal industry (excluding electronics), miscellaneous manufacturing, textile industry and in printing and publishing, and the increase was moderate in the paper and pulp industry, chemical industry, food, beverage and tobacco industry and in saw-milling and other timber industry. The performance of the electric and electronic appliance industry was astonishing, and at first sight the productivity growth would seem to be of a mushroom type in contrast to the clearly yeast-like productivity growth that resulted from the widespread use of electricity.[56] This view is reinforced when looking at the whole non-residential business sector. In the latter part of the 1990s the ICT-producer's LP growth experienced a major boost, but stayed level in ICT-using industries and back-stepped in other branches.[57]

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[54] Statistics Finland (1999): *On the Road to the Finnish Information Society II*, Helsinki: University Press.

[55] Maliranta, Mika and Rouvinen, Petri (2003): Productivity Effects of ICT in Finnish Business, *The Research Institute of the Finnish Economy (ETLA)*, Discussion Paper No. 852, May.

[56] Professor Harberger was the first one to coin the terms mushroom and yeast when talking of growth. Harberger, Arnold C. (1998): A Vision of the Growth Process, *The American Economic Review,* Vol. 88 (1), pp. 1-32.

[57] Jalava, Jukka (2003): Den nya ekonomin i Finland: produktion och användning av IKT, *Ekonomiska Samfundets Tidskrift,* Vol. 56 (1), pp. 17-24.

Table 2 Output per hours worked in manufacturing, compound average annual growth

	1974–1990 %	1990–2000 %	1990–2000 less 1974–1990 %-points
Manufacturing	**4.4**	**6.2**	**1.8**
Food, bev. and tobacco	3.4	4.9	1.5
Man. of textiles etc.	4.2	3.4	-0.8
Man. of wood etc.	4.3	4.8	0.5
Paper and pulp	4.8	6.0	1.2
Printing and publishing	3.7	3.4	-0.3
Man. of leather etc.	5.3	2.0	-3.3
Man. of chemicals etc.	3.6	4.7	1.1
Man of non-met. mineral prod.	3.5	3.0	-0.5
Metal industry (excl. electric)	4.6	3.4	-1.2
Electric and electronic appl. industry	5.2	14.2	9.0
Misc. manufacturing	3.6	2.5	-1.1

Source: Statistics Finland.

The 1990s was a decade of a shift in corporate governance of major Finnish firms from the Continental system, with a strong position of banks as sources of credit and significant shareholders, concentrated ownership and a limited amount of listed companies, to the Anglo-Saxon model, which is distinguished by a large number of listed firms, broad base of ownership, and above all the maximization of shareholder value. This shift was due to the rapid increase in the share of foreign ownership in Finnish listed firms. Whereas foreigners owned approximately 10 per cent of the market capitalization in 1992, the share rose to 70 per cent in 2000 (from whence it declined to 60 per cent in 2002). Empirical evidence shows that the foreign owned companies performed better than Finnish owned.[58] As the Finnish financial system became more diversified and stock oriented the prospect of innovative and possibly high-risk SMEs to attain financing improved in comparison with earlier bank dominated times. Thus the focus of Finnish industrial development shifted from investment-driven growth to innovation-driven growth, which was characterized by a rapid multi-factor productivity growth.[59]

[58] Ali-Yrkkö, Jyrki and Ylä-Anttila, Pekka (2003): Globalization of Business in a Small Country – Does Ownership Matter?, in Hyytinen, Ari and Pajarinen, Mika (eds.): *Financial Systems and Firm Performance: Theoretical and Empirical Perspectives,* ETLA B:200, Helsinki: Yliopistopaino.

[59] See: Hyytinen, Ari, Rouvinen, Petri, Toivanen, Otto and Ylä-Anttila, Pekka (2003): Does Financial Development Matter for Innovation and Economic Growth? Implications for Public Policy, in Hyytinen, Ari and Pajarinen, Mika (eds.): *Financial Systems and Firm Performance: Theoretical and Empirical Perspectives,* ETLA B:200, Helsinki: Yliopistopaino, and Jalava, Jukka (2002): "Accounting for Growth and Productivity: Finnish Multi-factor Productivity 1975-99", *Finnish Economic Papers,* Volume 15 (2), pp. 76-86.

4. Electricity vs. ICT: Decomposing the growth

To compare the productivity dynamics that the diffusion of electricity and ICT led to, we decompose labour productivity growth into the impacts of a component reflecting industries' internal productivity growth (we call it the within component), an employment share effect, i.e. the positive (negative) impact of the labour share increasing (decreasing) in a sub-industry with a level of LP higher than the aggregate level of LP (we call it the static shift effect), and a cross term, i.e. the combined impact of a shift in the sub-industries' labour share and LP growth rate (we call it the dynamic shift effect). Formally:

$$(LP_t - LP_{t-1})/LP_{t-1} = (\sum_{i=1}^{n}(LP_{i,t} - LP_{i,t-1})S_{i,t-1})/LP_{t-1} + (\sum_{i=1}^{n}(S_{i,t} - S_{i,t-1})LP_{i,t-1})/LP_{t-1} + (\sum_{i=1}^{n}(S_{i,t} - S_{i,t-1})(LP_{i,t} - LP_{i,t-1}))/LP_{t-1},$$

where LP is level of labour productivity, S_i is sub-industry i's share of hours worked and t denotes time. The first term on the right is the within component, the second term is the static shift effect and the third term is the dynamic shift effect.[60]

From 1901-1920 the cross-term was very negative indicating that industries with above average LP growth rates had diminishing labour shares (Figure 1 and Table 3). On the other hand, a positive employment share effect signified an increasing labour share in industries with an above average level of LP. All in all, structural change is much less marked in the other periods than in the 1900s and 1910s, the shift factors are furthermore positive in the latter two periods. Of the 1990s LP growth 5 percentage points can be attributed to structural change, i.e. that labour shifted to industries with either a higher level of or higher growth rate of LP.[61]

In the first two decades of the 20th century the paper and pulp industry alone accounted for almost half of the growth of the manufacturing industry's aggregate within component (Table 4). Another strong performer was the manufacture of wood. Also the food, beverage and tobacco industry, the textile industry and the non-metallic mineral product industry were strong performers. The largest drag on the aggregate within component came from the metal industry and printing and publishing. In the 1920s and 1930s the picture changed. The metal industry became the second largest contributor. The paper and pulp industry was still the biggest contributor, but its relative share declined. That was also the case with the former number two: manufacture of wood. The biggest decline in contribution was experienced by the textile industry. In the 1920s and 1930s no industries' within component contributed negatively to aggregate LP growth, as had been the case two decades ear-

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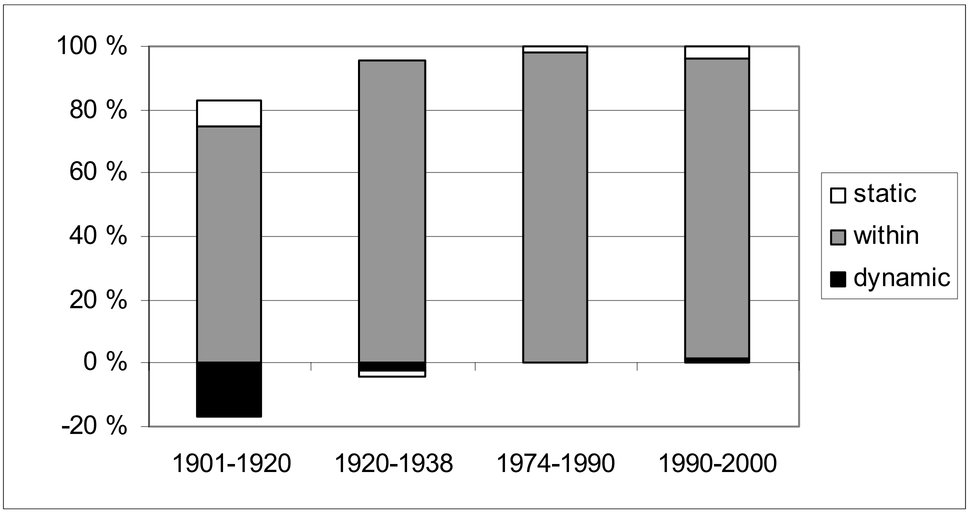
[60] Baily, Martin Neal, Bartelsman, Eric J., Haltiwanger, John (1996): Labour Productivity: Structural Change and Cyclical Dynamics, *National Bureau of Economic Research (NBER),* Working Paper 5503, March. For a nice overview of different productivity decomposition methods, see Maliranta: *Micro Level Dynamics.*

[61] Jalava, Jukka, Heikkinen, Sakari and Hjerppe, Riitta (2002): Technology and Structural Change: Productivity in the Finnish Manufacturing Industries, 1925-2000, *Transformation, Integration and Globalization Economic Research (TIGER),* Working Paper Series No. 34, December, see also Maliranta: *Micro Level Dynamics.*

lier. During the period 1974-1990 the non-electric metal industry was the growth engine of the within component of the aggregate manufacturing industry (Table 5). The paper and pulp industry was a distinct second, with the rest contributing evenly. In the 1990s almost all industries contributions decreased, as the electric and electronic appliance industry resumed the responsibility as engine of aggregate growth.

Figure 1 Decomposition of manufacturing industry labour productivity growth in 1901-1920, 1920-1938, 1974-1990 and 1990-2000



Sources: Own calculations, data for 1901-1938 from Hjerppe, Hjerppe, Mannermaa, Niitamo and Siltari (1976); the decompositions for 1974-2000 from Jalava, Heikkinen and Hjerppe (2002).

Table 3 The impact of structural change on labour productivity growth in the manufacturing industry in 1901-1920, 1920-1938, 1974-1990 and 1990-2000

	1901–1920 %	**1920–1938 %**	**1974–1990 %**	**1990–2000 %**
Within	113.6	104.6	97.7	94.9
Static	12.2	-1.7	2.2	3.8
Dynamic	-25.8	-2.8	0.2	1.2
Total	100.0	100.0	100.0	100.0

Sources: Own calculations, data for 1901-1938 from Hjerppe, Hjerppe, Mannermaa, Niitamo and Siltari (1976); the decompositions for 1974-2000 from Jalava, Heikkinen and Hjerppe (2002).

Table 4 Decomposition of manufacturing sub-industries' within components' contributions to labour productivity growth in 1901-1938

	1901–1920 %	1920–1938 %	1920–1938 less 1901–1920 %-points
Manufacturing	**100.0**	**100.0**	**0.0**
Food, bev. and tobacco	16.6	13.8	-2.8
Man. of textiles etc.	16.5	3.1	-13.4
Man. of wood etc.	23.2	14.4	-8.8
Paper and pulp	48.2	39.6	-8.6
Printing and publishing	-5.4	6.0	11.4
Man. of leather etc.	-0.8	1.9	2.7
Man. of chemicals etc.	2.1	1.5	-0.6
Man of non-met. mineral prod.	10.5	4.3	-6.2
Metal industry	-11.0	14.9	25.9
Misc. manufacturing	0.3	0.5	0.2

Source: Own calculations, data from Hjerppe, Hjerppe, Mannermaa, Niitamo and Siltari (1976).

Table 5 Decomposition of manufacturing sub-industries' within components' contributions to labour productivity growth in 1974-2000

	1974–1990 %	1990–2000 %	1990–2000 less 1974-1990 %-points
Manufacturing	**100.0**	**100.0**	**0.0**
Food, bev. and tobacco	8.8	8.3	-0.5
Man. of textiles etc.	6.6	1.7	-4.9
Man. of wood etc.	6.1	4.2	-1.9
Paper and pulp	19.8	19.6	-0.2
Printing and publishing	6.4	4.0	-2.4
Man. of leather etc.	4.8	1.2	-3.6
Man. of chemicals etc.	6.0	6.2	0.2
Man of non-met. mineral prod.	3.4	1.6	-1.8
Metal industry (excl. electric)	27.9	15.0	-12.9
Electric and electronic appl. industry	7.3	36.9	29.6
Misc. manufacturing	2.9	1.1	-1.8

Source: Jalava, Heikkinen and Hjerppe (2002).

5. Conclusion

In this paper we surveyed the diffusion of two GPT's, electricity and ICT, in the Finnish manufacturing industry. The full diffusion of electricity as motive power in the 1920s and 1930s led to a step-up of nearly 4 percentage points in manufacturing LP. Furthermore, all industries across the board gained in productivity. In contrast, when ICT was fully diffused by the end of the 20th century yeast-like productivity gains were invisible. In fact, LP slowed down in many industries, the notable exception of which is the electric and electronic appliance industry (Finland's main ICT-producer) that experienced a mushroom-like boost in its LP growth. The electronic industry is the natural place to find first signs of productivity gains, as it is the main producer of ICT in Finland. Similarly, LP growth surged in the electricity producing industry before gains were visible in the main electricity using manufacturing industries. Therefore there is, as the historical precedent has shown, likely to be a lag of several years before the productivity gains of the widespread adoption of ICT are visible.

We also performed a decomposition of LP growth during both GPT's periods of diffusion, and found that labour shifting to industries with differing levels or growth rates of LP explains less of aggregate LP change in 1920-1938 (and even less in 1974-2000) than it did in 1901-1920. Sub-industries contributions to the aggregate manufacturing industry's within component remain rather concentrated. In the first two decades of the 20th century paper and pulp and manufacture of wood contributed more than 70 percentage points. Two decades later paper and pulp, manufacture of wood and the metal industry contributed close to 70 percentage points of the within component. In the period 1974-1990 the non-electric metal industry and the paper and pulp industry contributed approximately 50 percentage points, and finally in 1990-2000 the electronic industry, the metal industry and the paper and pulp industry contributed more than 70 percentage points. As the within components share of the aggregate LP growth is even larger in the latter two periods than it was in the first two, we conclude that productivity growth is more concentrated as we are living in the times of diffused ICT, than our grandfathers and grandmothers experienced in the 1920s and 1930s. What started as a transfer of technology to a lately industrializing country through the importing of foreign machinery and equipment, the recruitment of foreign skilled workers and study trips abroad, has via a post-WWII investment-driven growth period successfully evolved into a growth driven by innovations.

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